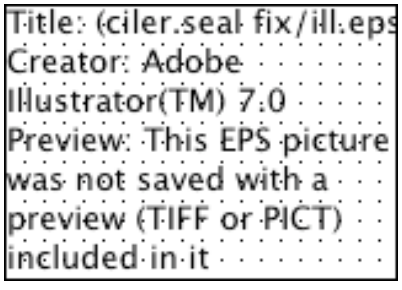
# COOPERATIVE INSTITUTE FOR LIMNOLOGY AND ECOSYSTEMS RESEARCH (CILER)

# ANNUAL REPORT

## NA17RJ1225 — Year Three
## July 1, 2003 to June 30, 2004

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# Cooperative Institute for Limnology and Ecosystems Research
# CILER

## Annual Report for NA17RJ1225
## Year Three: July 1, 2003 to June 30, 2004

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# Cooperative Institute for Limnology and Ecosystems Research
# CILER

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## ANNUAL REPORT for NA17RJ1225
## Year Three: July 1, 2003 to June 30, 2004

The Cooperative Institute for Limnology and Ecosystems Research (CILER), was established in 1989, and is the only joint institute with direct responsibilities for research in fresh water. CILER activities are not, however, limited to the limnetic environment; they also support research in estuarine and coastal marine environments. CILER research is focused in five areas: climate and large-lake dynamics, coastal and nearshore processes, large-lake ecosystem structure and function, remote sensing of large lake and coastal ocean dynamics, and marine environmental engineering.

CILER is a joint endeavor of the University of Michigan, Michigan State University, and the NOAA/Great Lakes Environmental Research Laboratory (GLERL). Its administrative offices are located at the University of Michigan in Ann Arbor. CILER promotes collaborative research between GLERL and scientists from throughout the Great Lakes Basin. Currently, CILER has more than 70 collaborators who represent almost every phase of limnological research. The Council of Fellows – which is composed of individuals from GLERL, the University of Michigan, and representatives from universities throughout the Great Lakes Basin – provides the primary intellectual guidance. In addition, CILER continues to support post-doctoral research fellows on various projects as well as a number of students including secondary, undergraduate and graduate students. Accomplishments for projects supported during the past year follow.

Summary of Joint Institute Staff by Head Count FY01

| Category | Number | B.S. | M.S. | Ph.D. |
|---|---|---|---|---|
| Research Scientists | 2 | | | 2 |
| Visiting Scientists | 0 | | | |
| Postdoctoral Research Fellows | 2 | | | 2 |
| Research Support Staff | 16 | 10 | 6 | |
| Administrative | 3 | 1 | 1 | |
| High School Students | 6 | | | |
| Undergraduate Students | 10 | | | |
| Graduate Students | 10 | | | |
| Totals | 49 | 11 | 7 | 4 |

## Summary of Joint Institute Staff by Head Count FY02

| Category | Number | B.S. | M.S. | Ph.D. |
|---|---|---|---|---|
| Research Scientists | 1 | | | 1 |
| Visiting Scientists | 0 | | | |
| Postdoctoral Research Fellows | 1 | | | 1 |
| Research Support Staff | 14 | 7 | 6 | |
| Administrative | 3 | 1 | 1 | |
| High School Students | 3 | | | |
| Undergraduate Students | 15 | | | |
| Graduate Students | 6 | | | |
| Totals | 43 | 8 | 7 | 2 |

## Summary of Joint Institute Staff by Head Count FY03

| Category | Number | B.S. | M.S. | Ph.D. |
|---|---|---|---|---|
| Research Scientists | 0 | 0 | 0 | 0 |
| Visiting Scientists | 0 | 0 | 0 | 0 |
| Postdoctoral Research Fellows | 0 | 0 | 0 | 0 |
| Research Support Staff | 7 | 3 | 3 | 0 |
| Administrative | 4 | 2 | 1 | 0 |
| High School Students | 3 | 0 | 0 | 0 |
| Undergraduate Students | 14 | 0 | 0 | 0 |
| Graduate Students | 4 | 2 | 2 | 0 |
| < 50% NOAA Support | 14 | 4 | 4 | 3 |
| Totals | 46 | 11 | 10 | 3 |
| Located at NOAA Lab | 33-GLERL | | | |
| Obtained NOAA employment | 0 | | | |

## Research Overview

This report details activities for the third year of our current cooperative agreement and covers the period from July 1, 2003 to June 30, 2004. During this period CILER administered 34 projects of which 25 supported activities within our five research themes and nine supported our Task I visiting fellows and science enhancement program. All of the Task I projects are a continuation of ongoing activities. Four of these projects were established during year one of the cooperative agreement as part of our science enhancement program. Science enhancement projects were awarded through a special call for proposals that establish research collaborations between Great Lakes basin faculty and NOAA scientists at the Great Lakes Environmental Research Laboratory. The program was supported by funds through the Office of Oceanic and Atmospheric Research. This program has been very successful in establishing new research collaborations at various institutions throughout the basin and has greatly supported our overall mission. Unfortunately, funds were not available to offer a new call for proposals in the past two fiscal years.

Other science enhancement activities that were conducted under Task I include our postdoctoral fellows program, our summer high school intern program, our Great Lakes Student Summer Fellows program for undergraduates and graduates, and a Great Lakes seminar series run in collaboration with NOAA-GLERL. All of these programs support the overall mission of CILER by providing increased opportunities for students and post-docs to participate in the Institutes research programs, and to help be a focal point for interactions between NOAA and the Great Lakes research community.

Of the 25 projects awarded within our five research tasks, fourteen projects were continuations of activities funded in the previous fiscal year and eleven projects were initiated within this reporting period. It should also be noted that we have already been awarded 18 new projects for the current year.

The total funding level for year three of our cooperative agreement activity was $948,171, slightly down from the previous two years of the agreement. However, CILER has also received approximately $1.05 million in sponsored funding external to the cooperative agreement during this reporting period. This funding supported three projects that still meet our overall research mission and involve either direct participation of other NOAA investigators or NOAA supported programs. Our biggest external sponsors is the Great Lakes Protection Fund which funded a research project co-managed by CILER and GLERL to examine the impact of ballast management practices for reducing the risk of invasive species introductions via foreign commercial vessels. A second project was awarded through the University of Maryland for our participation within the Alliance for Coastal Technologies (ACT). ACT is supported within NOAA's Coastal Service Center and is designed to advance the development of sensors and sensor technologies to support both coastal resource managers as well as efforts to enhance the observational capabilities being pursued within Ocean.US efforts. The third project was funded by the Consortium for Oceanographic Research and Education to support hosting and management of the Great Lakes Bowl for the National Ocean Sciences Bowl. The Great Lakes Bowl is one of 32 regional competitions in which 16 different high school teams compete in an academic quiz-game focusing on scientific and management issues related to oceans and large lakes.

A breakdown of funding by research task and theme for all three years of the current cooperative agreement is presented in Table 1. CILER's research tasks II-VI actually represent our specific research themes. CILER does not use the typical Task II and Task III designations to distinguish the nature of the collaboration with NOAA for a given project. However, most of our research projects involve direct collaboration of NOAA and CILER researchers. Exceptions are for some of the projects awarded through the Lake Champlain Research Consortium, and two individual projects funded by NOAA to researchers at Cornell University and the University of Michigan.

Table 1. Breakdown of funding by Task awarded to CILER for the current Cooperative Agreement, NA17RJ1225 for the period July 2001 through present.

| Task | Research Theme | # Projects | Funding | % Funding |
|---|---|---|---|---|
| I | Administration and Research Enhancement | 15 | 1,603,028 | 29 |
| II | Climate and Large-Lake Dynamics | 12 | 518,611 | 10 |
| III | Coastal and Nearshore Processes | 8 | 1,338,787 | 25 |
| IV | Large Lake Ecosystem Structure/Function | 21 | 1,275,671 | 23 |
| V | Remote Sensing / Coastal Ocean Dynamics | 2 | 332,946 | 6 |
| VI | Marine Environmental Engineering | 7 | 365,647 | 7 |
| | TOTALS | 65 | 5,434,690 | |

We currently have active research projects in all five of our thematic areas; however, our theme pertaining to ecosystem dynamics continues to be a major focus for CILER. Consequently most of our research programs support NOAA's Strategic Goal number one; Protect, Restore, and Manage the Use of Coastal and Ocean Resources Through Ecosystem-based Management. For each research project, we have identified which of the NOAA strategic goals is supported and these designations are listed under each project title within the report.

*Task II*. Seven projects were funded in our climate and large-lake dynamics theme. Two of these represent ongoing, multi-year collaborations focused on the development and application of hydrodynamics modeling in the Great Lakes. A new facet of this research area is the incorporation of ice thermodynamics and a much improved 2km grid scale resolution. These improvements should significantly improve the utility of circulation and thermal-structure models. The remaining five projects involve ongoing collaborations between NOAA and the Lake Champlain Research Consortium to investigate meteorological and hydrodynamic processes of Lake Champlain and its surrounding watershed. Four of these projects were initiated late in the project year and progress reports have not yet been developed.

*Task III.* There were only two active projects within our coastal and nearshore processes theme area during this project year. The first project focused on the development of improved sediment transport model and builds upon a significant body of work conducted under the previous COP funded EEGLE program for Lake Michigan. The second project was conducted under the Lake Champlain program and focused on understanding physical processes driving sediment transport in Shelburne Bay. Four new projects have been awarded in this research theme for this current year and we expect it to remain an active research area for CILER.

*Task IV*. The majority of research projects (eleven) were related to our ecosystem structure and function theme, with seven representing ongoing collaborations and five new projects awarded in 2003. The research covered many different aspects of the foodweb and the stressors that are producing undesirable impacts on these foodwebs and community structure. Three projects focused on the impacts of invasive zooplankton on pelagic food webs in Lake Michigan. The attention given to food web disruption by invasive species has increased significantly in the past few years and is a major issue for resource managers throughout the Great Lakes. Three additional proposals focused on disruption of

benthic food webs in the Great Lakes. Specifically, these projects examined the patterns and implications of the sudden and unexplained disappearance of *Diporeia*, a benthic amphipod that is a major food source for many larval fish species. Research showed how Whitefish diets have declined from primarily *Diporeia* (over 80 percent), to essentially zero in many of our survey regions. This loss of important diet source is viewed as a primary cause of the observed decline in the condition of this important fish species. Another project examined changing distributions and diets of sculpins in response to the loss of *Diporeia*. The last study focused on trying to identify causes for the disappearance. Research focused on the examination of the burden of epibionts found attached to the *Diporeia*. No significant relationships could be found to indicate that epibionts may be a direct cause of *Diporeia* declines. A seventh project continued a long and productive research program on improving our understanding and assessment of the toxicological effects of bioaccumulating organic contaminants. This research focused on the development of an effects-based approach to screen for potential hazard of bioaccumulated contaminants. These contaminants represent a legacy of pollution discharges to the Great Lakes during the heyday of the industrial development within the basin. An eighth project on post-depositional mobility of biochemically important materials focused on completion of laboratory analyses of samples that have been collected for the previous EEGLE and the Lake Michigan Mass Balance Study. Collectively these programs are providing the most comprehensive suite of chemical inventories, sedimentation rates, and sediment transport dynamics ever assembled within the Great Lakes. These studies are critical because the near surface sediments within the lakes contain huge inventories of important nutrients, as well as, harmful contaminants, and the resuspension and transport of these sediments has profound effects on the ecology and water quality of the ecosystem. A ninth project examined organic compounds that might serve as geochemical proxies to reconstruct paleo-environmental conditions within the Great Lakes. The goal of this study is to develop new research tools for understanding more recent climate change impacts. Another research project focused on improving our understanding of wetland ecosystem function by developing improved metrics for assessing the potential impacts of applying wetland restoration practices along coastal margins of the Great Lakes. The last project in this theme focused on developing statistically valid and precise estimates of lakewide and habitat-specific dreissenid abundance and biomass using new video and acoustic survey approaches. These improved biomass estimates are critical if we hope to develop realistic ecosystem forecasting models since dreissenids now represent a major new trophic component in the Great Lakes.

*Task V.* For our remote sensing and coastal ocean dynamics theme, we continued to support the long-term collaboration between CILER and NOAA-GLERL to develop and facilitate research products using remotely sensed data for the Great Lakes. Activities that utilize these data and products are quite diverse and include research on ice cover and ice classification, surface temperatures, turbidity, Great Lakes coastal forecasting, and algal blooms.

*Task VI.* The research activities within our marine environmental engineering theme continues to focus mainly on the assessment and control of aquatic invasive species (AIS) that result from commercial shipping activities within the Great Lakes. Two projects are focused on assessing the potential of using chemical disinfectants onboard ships as a treatment process for controlling invasive species introductions

and the risk to native species of discharging such treated ballast. A third project is examining the potential risk associated with ships that declare no-ballast-on-board and are subsequently devoid of any treatment procedures or screening under current federal policies. The remaining project within this theme is focused on developing passive acoustic methods for monitoring the distribution and movements of right whales. This research is sponsored by NOAA-NOS and was conducted under collaboration with experts in acoustical methods affiliated with Cornell University.

Publication Summary by Reporting Period

| | **JI Lead Author** | | | **NOAA Lead Author** | | | **Other Lead Author** | | |
|---|---|---|---|---|---|---|---|---|---|
| | FY01 | FY02 | FY03 | FY01 | FY02 | FY03 | FY01 | FY02 | FY03 |
| Peer-Reviewed | 10 | 16 | 8 | 2 | 5 | 2 | -- | -- | 12 |
| Non Peer-Reviewed | 1 | 7 | 1 | 1 | 4 | 6 | -- | -- | 0 |
| Total | 11 | 23 | 9 | 3 | 9 | 8 | -- | -- | 12 |

In additional to the total number of publications indicated in the above table (individual citations can be found under each project summary), there were 13 additional publications resulting from CILER research activities reported in prior annual reports that have been published subsequently. Citations for these publications are included in the appendix.

# ADMINISTRATION AND RESEARCH ENHANCEMENT

## CA4/I-02: PARTNERS-FOR-EXCELLENCE SUMMER HIGH SCHOOL INTERN PROGRAM

*Principal Investigator: Thomas F. Nalepa, Great Lakes Environmental Research Laboratory*

As part of a partnership with the Science Department of the Ann Arbor Public Schools, the Great Lakes Environmental Research Laboratory and the Cooperative Institute for Limnology and Ecosystems Research sponsored three high school interns to work with a GLERL or CILER mentor for the summer 2004:

| | | |
|---|---|---|
| Omer Ismail | Huron High School | Mentor: Thomas Nalepa |
| Feng Li | Pioneer High School | Mentor: Radka Pichlova |

The applicants went through a preliminary selection process by the Ann Arbor Public School system. Each applicant composed an essay that conveyed their interest in the internship and their qualifications, and was recommended by their science teacher. Final selections were made after interviews with GLERL or CILER mentors.

Each intern was assigned a mentor and performed research duties such as laboratory set-up, experiment preparation, data analysis, data coding, and computer input. Each intern summarized his or her experience in an essay for the Partners-For-Excellence Program.

## CA4/I-04: DYNAMICS OF LOCALIZED EDGE WAVES IN THE GREAT LAKES

*Co-Principal Investigators: David J. Schwab, Great Lakes Environmental Research Laboratory and Junaid As-Salek, University of Michigan*

NOAA Strategic Goal 3

During certain meteorological events, water level oscillations up to 1.5 m with periods of less than 2 hr have been observed in the Great Lakes. The squall line events of 7-11 March 1998, 29 May-2 June 1998 and 8-12 November 1998 in Lake Michigan, were analyzed by spectral and analytical methods. Dominant periods less than 2 hr were identified in the spectra of water level fluctuations, and coherencies among the spectral peaks of water levels of different station pairs were calculated to determine whether the oscillations were localized or basin wide. Explicit numerical calculations of normal mode periods and structures using a Lanczos procedure showed that the dominant periods in the observed data were consistent with the structures and periods of some of the calculated modes. The March 1998 and the November 1998 episodes showed higher surges with a gradual rise of water level, while the episode of May 1998 showed an abrupt rise in the water level at Calumet Harbor and about ten times higher spectral signature than the former two. Many of the high frequency modes had large amplitude at or near Calumet Harbor and the periods were close to the periods of edge waves that would be generated by a squall line similar to the May 1998 squall line. The trapping of energy and localized higher modes in a water body can work together to excite edge waves and localized seiches causing abrupt water level fluctuations.

## Publications

As-Salek, J.A. and D.J. Schwab. 2004. High frequency water level fluctuations in Lake Michigan. *ASCE Journal of Waterway, Port, Coastal, and Ocean Engineering* 45-53.

## Presentations

As-Salek, J.A., D.J. Schwab and D. Beletsky. 2001. Dynamics of high frequency water level fluctuations and storm surges in Lake Michigan. International Conference on Coastal Engineering. September 19-21. Rhodes, Greece.

As-Salek, J.A. 2000. GLERL Distinguished Scientist Seminar Series, November 21. Ann Arbor, Michigan.

As-Salek, J.A. 2000. Initial findings about high frequency fluctuation in Lake Michigan. EEGLE All-Hands Meeting. September. Ann Arbor, Michigan.

## Significant Interactions

Dr. Tad Munty, advisor to the World Meteorological Organization and UNESCO and former senior research scientist, Federal Government of Canada; Adam P. Fox, physical scientist, U.S. Army Corps of Engineers, Detroit, Michigan; and Jon Banitt, forecaster, National Weather Service, Marquette, Michigan.

## CA4/I-05SE: Investigations into the Decline of the Amphipod Diporeia in Lake Michigan: Changes in Potential Food Using the Sedimentary Record of Diatoms

*Co-Principal Investigators: Eugene F. Stoermer, University of Michigan; Thomas F. Nalepa, Great Lakes Environmental Research Laboratory; and John A. Robbins, Great Lakes Environmental Research Laboratory*

NOAA Strategic Goal 1

This project was initiated as a preliminary investigation of the probability that food chain effects, particularly changes in abundance and composition of phytoplankton being deposited into the benthic environment, was a factor in declines of the benthic amphipod *Diporeia* in Lake Michigan. *Diporeia* is a major food source for many fishes in the Great Lakes, and its decline is a matter of concern for fisheries managers and ecologists. Diatoms have often been used to document changes in the environment of lakes, including changes in their biota. They also have direct connection to the production of valued fish, in that they are a major source for the lipid food chain, which is important in boreal lakes. Three major hypotheses were investigated in this study:

- There has been a significant reduction in the total amount of lipid-rich potential food to the benthic community.
- There has been a significant change in the composition of the diatom rain to the benthic community.

- There are significant spatial differences in the amount and/or composition of potential food materials being produced and delivered to benthic communities in Lake Michigan.

On the basis of our results, the first hypothesis appears to require modification. Our results show that there was a significant decrease in diatom deposition from the late 1980s until ca. 1996. After this the concentration of diatom frustules in the sediments investigated increased to levels approximately similar to previous conditions. From this, it may be hypothesized that a reduction in the food base may be at least partially responsible for the observed *Diporeia* decline, but there is a significant time lag between measured response in the primary producer community (diatoms) and measurable effects in the invertebrate community.

Our results quite strongly support the second hypothesis. There is an apparent shift from previously very abundant large centric species to araphid pinnate and small centric diatoms. This is particularly significant because species of *Aulacoseira* can survive for extended periods in sediments (up to centuries), and the diatom spring bloom has been shown to support benthic production throughout the seasons. The species that have replaced spring-blooming *Aulacoseira* have lesser vegetative survival capabilities and probably lesser lipid content. This aspect of the present preliminary study certainly deserves further investigation and elaboration.

The third hypothesis is of interest because of the apparent shift in *Diporeia* abundance over time but was not supported by our results. Of the four cores investigated, only two preserved an adequate record of diatom deposition. The two cores that do contain apparently complete records exhibit only small differences, not beyond the level of probable error to the degree of accuracy allowed by our present enumeration protocol. It is possible that more extended counts could expose north - south differences, but we consider this unlikely. Advective transport, especially during the spring when diatom production is most rapid, probably results in deposition of material from a wide area at any given single site. Higher resolution counts may be useful to expose statistically reliable more records of low-abundance taxa, but discovery of regional differences, except on a broad scale, is unlikely using this technique.

## Publications

This project has not yet resulted in any formal publications. Data has been provided to NOAA collaborators, Drs. Thomas Nalepa and John Robbins, in electronic format for their consideration before a decision is reached as to the appropriate strategy for eventual publication. Our original thought was that this work would furnish the basis for a more extended proposal. It now appears that publication of the data developed so far may be justified. Because NOAA collaborators have ownership of the original samples and dating results, it will be necessary to reach general agreement as to the most appropriate strategy.

## Significant Interactions

Most potentially significant interactions have been with the EPA STAR project "Great Lakes Environmental Indicators." This is a large, multi-institutional effort

that includes a component on diatom communities in the nearshore zone. The results of research described here are pertinent.

## CA4/I-06SE: High-Resolution, Two-Way Nested Grid Model of Coupled Large Lake and Nearshore Processes

*Co-Principal Investigators: Nik D. Katopodes, University of Michigan and David J. Schwab, Great Lakes Environmental Research Laboratory*

NOAA Strategic Goal 1

We have engineered a nested scheme by developing a subspace projection method for time integration and nonreflective boundary conditions that allow information to travel freely through the computational boundaries of the nested grids. Applications are focused on Lake Michigan and the Muskegon River. The model for Lake Michigan is currently based on a fixed rectilinear grid with 2 km grid spacing while the estuarine model admits quadrilateral cells of variable size. The estuarine model can capture bathymetric and hydrodynamic features of the order of a few meters. However, with such fine resolution, it requires a very small time step that renders it inefficient for large-scale computations.

The present method aims at developing a nearly-continuous, nest-sequencing scheme by creating a series of variable grids. The finest grid adapts to the coastal features while the coarsest matches the lake grid. Therefore, the interface between the lake and estuary models requires no interpolation or filtering of any kind and all subspace projections occur in the estuarine model. The necessary nest ratio and level is determined locally by comparing the differences in the coarse and fine grid solutions. By computing the solution on two grids, one finer than the other, we parameterize the fine grid solution at the coarse grid level. Thus, the features of the fine grid solution are integrated into the coarse grid solution rather than simply sampled at nodes of collocation.

The model can incorporate several fine-grid implementations of the estuarine model all nested in the 2 km model for Lake Michigan. The latter can execute in parallel with coastal processes models in a computer-cluster configuration, in which all high-resolution nests advance to the time level of the Lake Michigan model before the latter moves to the next time step. Thus, at each time step, hydrodynamic data are available for input to the nests as boundary conditions. The nests process hydrodynamic and water quality information at much finer spatial and temporal resolution and, when they reach the next time step of the Lake Michigan model, they transfer this information to the whole lake simulation.

### Publications

Kao, K.C. and N.D. Katopodes. 2004. Interface method for two-way nesting of hydrodynamic models. (in preparation)

Katopodes, N.D., K.C. Kao, D. Schwab, and S. Bradford. 2003. Nesting of hydrodynamic models with multiple scales. Estuarine and Coastal Modeling. Monterey, California. November.

Katopodes, N.D. and K.C. Kao. 2003. Two-way nested grid model of coupled lake and nearshore processes. Engineering Mechanics Conference, ASCE, New York. July.

## Presentations

Katopodes, N.D. 2002. Contaminant transport by density currents. The 6th International Conference on Protection and Restoration of the Environment. Skiathos, Greece. July.

Katopodes, N.D. 2002. Transboundary transport of groundwater pollutants by lake currents. UCOWR-ERI/ASCE Special Joint Conference. Traverse City, Michigan. July.

## Significant Interactions

Our main interaction has been with the NOAA/Great Lakes Environmental Research Laboratory. Some interactions took place with the National Weather Service and the USDA in connection with the proposals listed below.

- NOAA: Flood forecasting by grid nesting of weather, watershed, and river model; 36 months; $372,000.
- USDA: Multiple-scale model for watershed processes; 48 months; $350,518.

## Student Participation

K.C. Kao was advanced to candidacy; the topic of his PhD dissertation is identical to this project.

## CA4/I-07SE: Molecular and Isotopic Paleotemperature Proxies in the Great Lakes Sediments: Keys to Climate Prediction?

*Co-Principal Investigators: Philip A. Meyers, University of Michigan and Brian J. Eadie, Great Lakes Environmental Research Laboratory*

NOAA Strategic Goal 1

The oxygen isotopic composition of calcium carbonate that precipitates in hardwater lakes is affected by meteorologic factors whereas the inorganic and organic carbon and nitrogen isotopic compositions of lake sediments are influenced by biological productivity within the lake. We have measured the isotopic compositions at 1 cm intervals in three cores of Lake Erie sediment that span the period 1895 to 1991 and we have compared these parameters to meteorological records and to mass accumulation rates of the aquatic productivity proxies, organic carbon and calcium carbonate. Calcite $\delta^{18}O$ values that become smaller from 1980 to 1991 in the absence of evidence of a summer temperature change suggest a decadal change in air mass trajectories. In contrast, a shift to large $\delta^{18}O$ values from 1905 to 1910 that is accompanied by diminished calcite precipitation and higher lake levels suggest a period of cooler summer temperatures. Increases in inorganic and organic $\delta^{13}C$

values, $\delta^{15}N$ values, and organic carbon accumulation starting in 1960 reflect the heightened productivity caused by anthropogenic nutrient increases to lake Erie.

## Publications

Knowlton, C.K., P.A. Meyers, B.J. Eadie, and J.A. Robbins. 2004. Record of changes in 20th century moisture delivery to Lake Erie from sedimentary calcite $\delta^{18}O$ patterns. *Journal of Paleolimnology* (in preparation).

Knowlton, C.K., P.A. Meyers, B.J. Eadie, J.A. Robbins, and M. Lansing. 2004. Impacts of eutrophication on carbon burial in Lake Erie. *Limnology and Oceanography* (in preparation).

## Presentations

Knowlton, C., P.A. Meyers, B.J. Eadie, and J.A. Robbins. 2003. Oxygen, carbon, and nitrogen isotopic evidence of environmental changes in eastern Lake Erie over the past century. Annual fall meeting of the American Geophysical Union, San Francisco, CA. Abstract published as *EOS, Transactions American Geophysical Union* 84(46), Fall Meeting Supplement, Abstract B41A-02.

## Significant Interactions

Various elements of the research done during the course of this project have led to fruitful interactions with the lake sediment paleoclimate study directed by Dr. Jane Teranes, Scripps Institution of Oceanography, and the lake sediment paleo-productivity studies directed by Professors Nathaniel Ostrom and Peggy Ostrom, Michigan State University.

## Additional Funding

No additional funding has yet been received. A proposal (Multi-proxy record of millennial and centennial climate changes in sediments of the Great Lakes Region) has been submitted to NSF Division of Atmospheric Sciences.

## Student Participation

Christina Knowlton. May 2003. M.S. Department of Geological Sciences, University of Michigan. Molecular and isotopic paleoenvironmental proxies in Lake Erie sediments. Currently employed as a hydrologist by the US Geological Survey in Lincoln, NE.

## CA4/I-08SE: Improving Interpretation of Bioaccumulation Data through Development of Tissue-Residue Toxicity Relationships

*Principal Investigators: Lance J. Schuler, Southern Illinois University; Peter F. Landrum, Great Lakes Environmental Research Laboratory; and, Michael J. Lydy, Southern Illinois University*

NOAA Strategic Goal 1

The internal lethal body residue has been recognized as a potential dose metric for toxicological assessments. Fluoranthene was selected for use in evaluating the time-dependent toxicity of PAHs in three freshwater invertebrates species: *Hyalella azteca*, *Chironomus tentans*, and *Diporeia* spp. The lethal body residue required for 50 percent mortality ($LR_{50}$) was not constant and decreased with exposure time for all species. The $LR_{50}$ values ranged approximately two orders of magnitude on a wet weight basis among species for the same duration of exposure. Fluoranthene was most toxic to *C. tentans* having $LR_{50}$ values of 0.43 μmol $g^{-1}$ at 2 d and 0.17 μmol $g^{-1}$ at 10 d and least toxic to *Diporeia* spp. Having values of 9.97 μmol $g^{-1}$ at 10 d and 3.67 μmol $g^{-1}$ at 28 d. The $LR_{50}$ values for H. azteca were intermediate with residues ranging from 3.19 μmol $g^{-1}$ at 5 d and 0.86 μmol $g^{-1}$ at 28 d. When *Diporeia* and *H. azteca* $LR_{50}$ values were compared at steady state, there was no statistical difference but *C. tentans* was significantly more sensitive. The information collected from this study will permit a greater understanding of residue-response relationships in addition to relative species sensitivity.

### Publications

Schuler, L.J., P.F. Landrum and M.J. Lydy. 2004. Time-dependent toxicity of fluoranthene to *Hyalella azteca*, *Chironomus tentans* and *Diporeia* spp. *Environmental Science and Technology*. (submitted)

Wilcoxen, S.E., P.G. Meier and P.F. Landrum. 2003. The toxicity of fluoranthene to *Hyalella azteca* in sediment and water-only exposures under varying light spectra. *Ecotoxicology and Environmental Safety* 54: 105-117.

### Presentations

Schuler, L.J., P.F. Landrum and M.J. Lydy. 2003. Time-dependent toxicity of fluoranthene to *Hyallella azteca*, *Chironomus tentans* and *Diporeia* spp. Society of Environmental Toxicology and Chemistry (SETAC) National Meeting. November. Austin, Texas.

Schuler, L.J., P.F. Landrum and M.J. Lydy. 2003. Time-dependent toxicity of fluoranthene using *Hyalella azteca*. Society of Environmental Toxicology and Chemistry (SETAC) National Meeting. November. Austin, Texas.

Schuler, L.J., P.F. Landrum and M.J. Lydy. 2003. Body residues: implications in ecotoxicology and hazard assessment. Great Lakes Seminar Series at NOAA Great Lakes Environmental Research Laboratory. October 24. Ann Arbor, Michigan.

Schuler, L.J., P.F. Landrum and M.J. Lydy. 2003. Time-dependent toxicity of fluoranthene in freshwater invertebrates. Society of Environmental Toxicology and Chemistry, Regional Meeting. May. Cincinnati, Ohio.

Schuler, L.J. and M.J. Lydy. 2002. An assessment of the time-dependent toxicity of fluoranthene using *Hyalella azteca*. Society of Environmental Toxicology and Chemistry (SETAC) National Meeting. November. Salt Lake City, Utah.

Schuler, L.J. and M.J. Lydy. 2002. Preliminary assessment of the time-dependent toxicity of fluoranthene using Hyalella azteca. Society of Environmental Toxicology and Chemistry (SETAC) Regional Meeting. May. Vicksburg, Mississippi.

### Significant Interactions

This project has generated significant amounts of collaboration between Great Lakes Environmental Research Laboratory and Southern Illinois University. In addition, Dr. Landrum has established an adjunct professorship within the Department of Zoology at Southern Illinois University and is a dissertation committee member for Lance Schuler.

### Additional Funding

Society of Environmental Toxicology and Chemistry (SETAC) and Proctor & Gamble Company Global Fellowship for Doctoral Research in Environmental Science.

### Student Interaction

Schuler, Lance. Ph.D. expected 2005. Dissertation, "Collection and interpretation of body residue-effects data for use in hazard assessment." Department of Zoology and Fisheries and Illinois Aquaculture Center, Southern Illinois University.

## CA4/I-11: Great Lakes Summer Student Fellowship Program

*Principal Investigators: Thomas H. Johengen, University of Michigan and Stephen B. Brandt, Great Lakes Environmental Research Laboratory*

The Cooperative Institute for Limnology and Ecosystems Research and the Great Lakes Environmental Research Laboratory implemented the Great Lakes Summer Student Fellowship Program in 1998. To date, there have been 96 fellows supported by this program.

For summer 2004, 20 student fellow positions were selected from 71 applications, with preference given to currently enrolled undergraduate students or those who have recently graduated. Graduate applications were also considered. Of those selected, 12 were undergraduates and eight were graduate students (seven master's and one doctoral); ten were female and ten were male. Each student fellow worked under the mentorship of an individual scientist or professional in a broad range of fields.

| Student Fellow | Academic Institution | Fellowship Field |
|---|---|---|
| Sayan Bhattacharyya | University of Michigan | Food Web Modeler |
| Amy Croover | Salish Kootenai College | Toxicologist |
| Angela Dykema | Michigan State University | Outreach Specialist |
| Rosemary Fanelli | SUNY-Brockport | Bathymetry Cartographer |
| Lee Heppe | University of Wisconsin-Milwaukee | Electronics Engineer |
| Jonathan Maruska | University of Minnesota-Duluth | Aquatic Biologist |
| Erynn Maynard | SUNY-Buffalo | Aquatic Biologist |
| Naftali Mwaniki | Ferris State University | Data Analyst |
| Jyoteshwar Nagol | University of Toledo | Remote Sensing Technician |
| Elizabeth Oswald | University of Michigan | Electronics Engineer |
| Jacqueline Piero | East Carolina University | Maritime Historian |
| Mustafa Rahim | Western Michigan University | GIS Operator |
| Julie Reichert | Wayne State University | Aquatic Ecologist |
| Quy Thai | Wayne State University | Aquatic Biologist |
| Joel Trubilowicz | Michigan Technological University | Electronics Engineer |
| Jenna Voss | University of Michigan | Aquatic Biologist |
| Yingjie Wei | Western Michigan University | Computer Programmer |
| John White | Carthage College | Data Analyst |
| Jason Williams | Augustana College | Aquatic Ecologist |
| Ling Yao | University of Toledo | Remote Sensing Technician |

All student fellows were University of Michigan guest students working with either a GLERL or CILER mentor mostly in Ann Arbor, Michigan except for one fellow who worked in Alpena, Michigan, one fellow who worked in Muskegon, Michigan, two fellows who worked in Kalamazoo, Michigan, and one fellow who worked in Milwaukee, Wisconsin.

## CA4/I-12: Great Lakes Seminar Series

*Principal Investigators: David F. Reid, Great Lakes Environmental Research Laboratory; Rochelle Sturtevant, Michigan Sea Grant College Program and Thomas H. Johengen, University of Michigan*

One of the most productive means to enhance research collaborations between NOAA and the academic research community is to facilitate and encourage communication and networking. One approach to doing this is the implementation of a seminar series of invited speakers and targeted topical areas of focus. CILER has co-sponsored the Great Lakes Seminar Series since July 2001. Speakers are solicited in a broad range of disciplines encompassing all of our research theme areas. In FY 2004, __ speakers presented seminars.

### Seminar Presentations

Analyses of floc characteristics and suspended particle behavior. July 22, 2003. Rajat K. Chakraborti, State University of New York at Buffalo.

If only benthos could talk, fish farming and azoic benthic communities. August 19, 2003. Sandor Mulsow, International Atomic Energy Agency, Laboratory at Monaco.

Evaluating changes in winter climatology and hydrology of the Lake Michigan basin from 1948 to 2000. September 11, 2003. Erin Argyilan, University of Illinois at Chicago.

Calibrating in situ fluorescence to chlorophyll concentration for lake Michigan. September 22, 2003. Leah Welty, University of Chicago.

Newly discovered and corroborated deleterious effects of zebra mussels on lake ecosystems. October 14, 2003. David Raikow, NOAA/Great Lakes Environmental Research Laboratory.

Historical response of zooplankton communities to ecological change in Lake Victoria (East Africa). October 15, 2003. Thomas Bridgeman, University of Toledo.

Body residues: implications in ecotoxicology and hazard assessment. October 24, 2003. Lance J. Schuler, Southern Illinois University.

Oxygen concentration and demand in Lake Erie sediments. November 12, 2003. Gerald Matisoff, Case Western Reserve University.

The National Ocean Service Great Lakes Observing Network. November 13, 2003. Mark Bushnell and Jennifer Werner, NOAA/National Ocean Service.

The benthification of freshwater lakes: exotics turning ecosystems upside down. November 20, 2003. Christine Mayer, University of Toledo Lake Erie Center.

Observations of steep wave statistics in open ocean waters. January 14, 2004. Nicholas Scott, Woods Hole Oceanographic Institution.

NOAA/Great Lakes Environmental Research Lab's distributed hydrology model for the Maumee River Watershed. February 19, 2004. Thomas E. Croley II, NOAA/Great Lakes Environmental Research Laboratory.

Numerical modeling of mixed sediment resuspension, transport, and deposition during the March 1998 episodic event in southern Lake Michigan. February 26, 2004. Cheegwan Lee, University of Michigan.

A physical-biological coupling for the west Florida Shelf and a new development of turbulence-wave interaction and its application. March 16, 2004. Le Ly, Naval Postgraduate School.

Great Lakes coastal observation systems and microsensor development. March 18, 2004. Steven Ruberg, NOAA/Great Lakes Environmental Research Laboratory.

A carbon budget for Lake Malawi, Africa. April 8, 2004. Harvey Bootsma, University of Wisconsin-Milwaukee.

Recent investigations into the use of body residues as a dose metric. April 15, 2004. Peter Landrum, NOAA/Great Lakes Environmental Research Laboratory.

Lacustrine organic matter bulk and isotopic markers of environmental processes and paleoenvironmental changes: examples from Lagoa do Caco (Maranhao State, Brazil). May 11, 2004. Abdel Sifeddine, Institut de Recherche pour le Developpement, France.

Biological invasions in the Great Lakes: science, management, and policy. May 20, 2004. David Raikow, NOAA/Great Lakes Environmental Research Laboratory.

Winter operation of water intakes in the nearshore zone of the Great Lakes. June 10, 2004. Steven F. Daly, Cold Regions Research and Engineering Center, Hanover, New Hampshire.

Sedimentary signatures of particle transport and sorting in southern Lake Michigan. June 17, 2004. John Robbins, NOAA/Great Lakes Environmental Research Laboratory.

Compartments in food webs: how they help quantify structural changes in the food web of southeastern Lake Michigan after the invasion of zebra mussels and bythotrephes. June 29, 2004. Ann Krause, Michigan State University.

## CA4/I-13: A Collaborative Faculty Position with Michigan State University to Enhance Research and Outreach Activities Between NOAA and Universities throughout the Great Lakes Basin.

*Principal Investigators: Thomas H. Johengen, University of Michigan; William Taylor, Michigan State University; and Stephen B. Brandt, Great Lakes Environmental Research Laboratory*

NOAA Strategic Goal 1

To extend the commitment and responsibilities of CILER to complement and coordinate the research activities between the Great Lakes Environmental Research Laboratory and universities throughout the Great Lakes basin, the creation of a collaborative faculty position was funded. This position focused on the development and coordination of research, teaching, and outreach programs between NOAA and Michigan State University that emphasize the development, testing, and use of Great Lakes aquatic system models, with additional research in marine coastal and estuarine systems. This research program facilitated the use of computer and laboratory facilities by collaborating with GLERL investigators and maintaining an active presence in the Department of Fisheries and Wildlife at Michigan State University. Extensive collaboration served to build complementary research programs that included community, population, and ecosystem ecology; limnology and oceanography; modeling of dynamic ecological systems; and aquatic ecology. The teaching program included classroom instruction and the mentoring and advising of graduate students. The outreach component included serving on scientific review committees as well as providing extension and outreach to international, national, and state agencies involved in research and management of the Great Lakes and coastal ecosystems.

This collaborative faculty position is currently filled by Dr. Scott Peacor, an ecosystem modeler. Dr. Peacor's research interests involve the study of aquatic

ecosystems, and the development of mathematical frameworks to understand species interactions and their consequences to food web structure and dynamics. He examines how animal species representing diverse taxa in disparate systems are confronted with and respond similarly to common ecosystem processes. By representing such processes with conceptual and mathematical frameworks, they are made explicit, are clarified, and comparison between systems that can yield additional insight is facilitated. He also utilizes controlled experiments to validate model predictions, to help illustrate their connection with natural systems, and to expose unforeseen processes when experimental results do not match model predictions.

## Publications

Pfister, C.A. and S.D. Peacor. 2003. Variable performance of individuals: the role of population density and endogenously formed landscape heterogeneity. *Journal of Animal Ecology* 72: 725-735.

Werner, E.E. and S.D. Peacor. 2003. A review of trait-mediated indirect interactions in ecological communities. *Ecology* 84(5): 1083-1100.

Peacor, S.D. 2003. 2003. Phenotypic modifications to conspecific density arising from predation risk assessment. *Oikos* 100(2): 409-415.

## CLIMATE AND LARGE-LAKE DYNAMICS

Research conducted by CILER under this task originally focused on climate change, but has been broadened to include research involved with the interaction of large lakes and the atmosphere and their attendant influence on physical processes. Because large lakes of the world have a decided impact on their surrounding microclimate, and likewise are heavily influenced by regional climate, understanding the relationships between these large lakes goes beyond the scope of climate change. Included in this task are activities such as the study of heat flux into and out of large lakes, wind forecasts, hydrodynamic forecasting and coupled hydrosphere-atmosphere models.

### CA4/II-01: The Impact of Episodic Events on Nearshore-Offshore Transport in the Great Lakes: Hydrodynamic Modeling Program

*Co-Principal Investigators: Dmitry Beletsky, University of Michigan and David J. Schwab, Great Lakes Environmental Research Laboratory*

NOAA Strategic Goal 1

Years one through four of this project were funded through CILER's cooperative agreement NA67RJ0148. Year five is funded through this current cooperative agreement. This study is part of the joint NSF/OCE NOAA/COP Great Lakes Project, a five-year multidisciplinary program on the impact of episodic events on the coastal ecosystem in the Great Lakes (EEGLE, Episodic Events - Great Lakes Experiment). The purpose of this project is to create a numerical modeling effort (in close cooperation with the observational program, meteorological modeling, sediment transport modeling, and ecological modeling), to identify, quantify, and develop prediction tools for the primary physical processes responsible for nearshore-offshore transport of biogeochemically important materials in the Great Lakes, and in Lake Michigan in particular. The hydrodynamic modeling program is designed to test the following specific hypothesis: that the forced, two-gyre vorticity wave response of the lake to episodic wind events, occasionally modified by stratification, is a major mechanism for nearshore-offshore transport in the Great Lakes**.** The recurrent springtime appearance of an extensive turbidity plume in southern Lake Michigan (Eadie et al, 1996) provides a unique opportunity to examine the two-gyre vorticity wave hypothesis during a period when a large volume of suspended material can act as a natural tracer of nearshore-offshore circulation patterns. The program studied this phenomena in Lake Michigan during winter and spring transition periods (thermal bar), in order to be able to compare cross-margin transport generated by purely barotropic processes in the winter to transport later in the spring when baroclinic processes may be more important.

A 2km bathymetric grid of Lake Michigan was prepared for use by all physical and biological models in the EEGLE project. The grid is based on the new, high-resolution bathymetry released by the National Geophysical Data Center (NOAA/NDGC). Meteorological data were collected and analyzed for the 1998-2000 period (including March 1998 output from the mesoscale meteorological model

MM5 for Lake Michigan). Circulation and wave models were linked to a sediment transport model. We performed wave, hydrodynamic and sediment transport model simulations for the March-April 1998 and March-April 1999 sediment plume events in Lake Michigan on a 2 km grid. Products are available at http://www.glerl.noaa.gov/eegle. Hydrodynamic model results showed significant offshore flow during these episodes. We also performed model simulations for the whole 1998-2000 EEGLE field program period and began analysis of 1998-2000 current observations in Lake Michigan to evaluate hydrodynamic model performance. Model run with MM5 winds during a six-day period in March 1998 showed improvement in simulated currents over the model run with objectively analyzed winds. Therefore, we obtained 30-day long MM5 winds for the resuspension event in March 1999 to explore this topic further. Model results in 199 were consistent with 1998 findings: model errors were reduced with MM5 winds were used. We also began comparison of modeled surface currents with HF-radar derived currents during the 2000 resuspension event. Particle trajectory model was applied for April-May 1999 and results were compared with drifter observations in southern Lake Michigan. The results of 2000 model runs were provided to HyrdoQual, Inc. and Baird & Associates.

Sediment transport model results showed that wind waves are primarily responsible for sediment resuspension while currents move sediments along shore and offshore and therefore play an important role in creating the net erosion/deposition pattern in the lake. The sediment transport model produced a sediment erosion /deposition pattern qualitatively close to existing observations with most sediment deposition along the east shore of Lake Michigan. We performed model simulations of sediment transport in idealized basins in order to determine the cause of asymmetry of sediment deposition patterns in Lake Michigan. Eight sediment resuspension episodes were identified in 1998-2000 based on sediment model resuspension calculation. The 3D particle trajectory model was run for a three-day period corresponding to the main events to visualize nearshore-offshore physical transport.

The circulation model was revised as part of our work on creating the Great Lakes Modeling System (a system of models to hindcast, nowcast and forecast physical and biological conditions of the Great Lakes). A 1-D physical model was developed and linked to a biological model. A 3-D model results were also used in the biological model. Steady flow boundary conditions were implemented for 18 inflow tributaries and two outflows on the 2 km Lake Michigan grid. A copy of the circulation model was provided to Ohio State University to be used in the nowcast/forecast system for Lake Michigan.

## Publications

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Beletsky, D., D.J. Schwab, P.J. Roebber, M.S. McCormick, G.S. Miller and J.H. Saylor. 2003. Modeling wind-driven circulation during the March 1998 sediment resuspension event in Lake Michigan. *J. Geophys. Res.* 108(C2): 3038.

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Chen, C., R. Ji, D.J. Schwab, D. Beletsky, G.L. Fahnenstiel, M. Jiang, T.H. Johengen, H.A. Vanderploeg, B.J. Eadie, J. Wells Budd, M. Bundy, W. Gardner, J.B. Cotner and P. Lavrentyev. 2002. A model study of the coupled biological and physical dynamics in Lake Michigan. *Ecological Modeling* 152:145-168.

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Beletsky, D. 2001. Modeling wind-driven circulation in Lake Ladoga. *Boreal Environment Research* 6: 307-316.

Lou, J., D.J. Schwab, D. Beletsky and N. Hawley. 2000. A model of sediment resuspension and transport dynamics in southern Lake Michigan. *J. Geophys. Res*. March 15, 105(C3): 6591-6610.

Schwab, D.J., D. Beletsky and J. Lou. 2000. The 1998 coastal turbidity plume in Lake Michigan. *Estuarine Coastal and Shelf Science* 50: 49-58.

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Beletsky, D., J.H. Saylor and D.J. Schwab. 1999. Mean circulation in the Great Lakes. *J. Great Lakes Research* 25: 78-93.

Beletsky, D., K.K. Lee and D.J. Schwab. 1999. Large-scale circulation. In: D.C.L. Lam and W.M. Schertzer (eds.) Potential Climatic Effects on Lake Hydrodynamics and Water Quality, ASCE, Reston, Virginia, 4: 1-41.

Lou, J., D.J. Schwab and D. Beletsky. 1999. Suspended sediment transport modeling in Lake Michigan. *The 1999 Canadian Coastal Conference*, May 19-22, Victoria, British Columbia, p. 391-405.

Presentations

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Beletsky, D. 2003. Modeling thermal structure, circulation and larval transport in Lake Michigan. Great Lakes WATER Institute Seminar Series, University of Wisconsin-Milwaukee. June 4. Milwaukee, Wisconsin.

Beletsky, D. and D.J. Schwab. 2003. Retrospective (1953-2002) hydrodynamic modeling of Lake Erie. NOAA/COP Great Lakes Issues Workshop, University of Michigan. January 20-21. Ann Arbor, Michigan.

Beletsky, D. 2002. Sediment resuspension events in Lake Michigan. Lecture to a visiting limnology class at Bowling Green State University. December 18. Ann Arbor, Michigan.

Schwab, D.J., B.M. Lesht, J. Stroud and D. Beletsky. 2002. The use of SeaWiFS imagery and a numerical sediment dynamics model for studying coastal processes in Lake Michigan. The 34th COSPAR Scientific Assembly. October 10-19. Austin, Texas.

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Eadie B.J, D.J. Schwab, P.J. Roebber and D. Beletsky. 2001. Climatology of resuspension events in Lake Michigan. The 2001 EEGLE-KITES Workshop. September 20-23. Houghton, Michigan.

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Schwab, D.J and D. Beletsky. 2001. Sediment transport modeling in Lake Michigan. LMMBS sediment modeling workshop. January 24-25. Ann Arbor, Michigan.

Beletsky, D. 2000. Hydrodynamic and sediment transport modeling for the 1998 Lake Michigan coastal turbidity plume event. NOAA review of the Great Lakes Environmental Research Laboratory. December 4-5. Ann Arbor, Michigan.

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Beletsky, D., D.J. Schwab, K.W. Bedford, C. Chen, Y.P. Chu, J. Lou, P.J. Roebber and R. Ji. 2000. Physical-biological modeling of Lake Michigan in the EEGLE program. The 43rd Conference of International Association for Great Lakes Research. May 21-26. Cornwall, Ontario, Canada.

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Schwab, D.J. and D. Beletsky. 1997. EEGLE hydrodynamic modeling program. The 1997 NOAA/NSF EEGLE-KITES Workshop. August 10-12. Milwaukee, Wisconsin.

Significant Interactions

We collaborated with Dr. Paul Roebber, University of Wisconsin-Milwaukee on improving the wind fields in the Lake Michigan circulation model; Dr. Changshen Chen, University of Georgia on physical-biological modeling; and Dr. John Vesecky, University of Michigan on model-HF radar current comparison. A copy of the circulation model was provided to Ohio State University to be used in the nowcast/forecast system for Lake Michigan. Results of the 2000 model runs were provided to HydroQual, Inc., and Baird & Associates to support their complementary research efforts.

## CA4/II-02: Modeling Ice Thermodynamics and Transport in the Great Lakes

*Principal Investigators: Dmitry Beletsky, University of Michigan and David J. Schwab, NOAA/Great Lakes Environmental Research Laboratory*

NOAA Strategic Goal 1

New 2 km numerical model grid was developed for Lake Erie. The modal has 23 major tributaries and two outflows. Initially, we will use climatological runoff data to drive the model. The model was run for the April to December 1994 period to test circulation and thermal structure calculations. We are in the process of comparing

model thermal structure against several seasonal temperature observations in western, central, and eastern Lake Erie.

### Significant Interactions

We collaborated with Dr. L. Leon of the University of Waterloo on the hydro-dynamic model simulations of thermal structure in Lake Erie.

## CA4/II-04: Final Phase of the Lagrangian Drifters Pilot Program

*Principal Investigator: Thomas O. Manley, Middlebury College*

NOAA Strategic Goal 1

### Background

The mean circulation patterns of Lake Champlain have been very difficult to obtain using long-term Eulerian (fixed) mooring systems due of the large oscillatory motions created by the internal seiche (Hunkins et al, 1998; Hunkins et al., 1999; Manley et al., 1999a). In May of 2000, a two-year pilot program involving the use of deep-ocean Lagrangian drifter (neutrally-buoyant free-drifter) technology, known as the RAFOS program, began within the basin. This initiative was supported by the USGS, Middlebury College, and the Lintilhac Foundation and involved researchers from the Laboratoire D'Oceanologie Dynamique et de Climatologie (LODYC, Paris; Dr. Jean Claude Gascard), Seascan (Mr. Pierre Tillier of Falmouth Massachusetts), LDEO of Columbia University (Dr. Ken Hunkins), NOAA GLERL (Dr. Jim Saylor), and Middlebury College (Tom Manley).

The RAFOS program represents a high ranking on the LCRC's hydrodynamic priority list. The development of a Lagrangian free-drifter program will add a new dimension to our understanding of circulation within Lake Champlain. Eulerian measurements (moorings) cannot define water particle motion past any reasonable distance away from the site or even net circulation within a highly oscillatory field of currents such as found in Lake Champlain. Being able to track water particles over time within a major sector of the Main Lake will finally provide this needed information which can then be utilized in basic research, modeling and management related issues.

The initial program was designed for two summer field programs over two years. The first phase was to verify if acoustic propagation techniques used in the deep ocean would be capable of supporting an acoustic 'net' that could be used for tracking underwater drifters in Lake Champlain. The use of underwater acoustics is essential to the success of the program in that the underwater drifters have to be able to detect and verify the 'encoded' signals emitted by the various sound sources moored at precise locations within the lake. The location of the drifter over time can then be determined using triangulation techniques knowing the distances from the various sound sources. The pilot program was designed to be completed over two years of field-testing. During the first year, a commonly used deep-ocean system operating at 780 Hz and borrowed from LOYDC was used. During the initial phase of the program, a few of the standard deep-ocean neutrally-buoyant drifters would also be tested during a short (1-2 week) 'free-drifting' test period. The second year of

the program was to be that of a deploying an observational array of 4-6 sound sources and 4-6 drifters that would be used to begin the study of Main Lake circulation within the epilimnion and hypolimnion.

## Prior Results

The results of the first-year pilot study were encouraging, however, there was one setback that surprised all of the researchers and technical support staff at LOYDC and WHOI; the standard deep-ocean drifter to be used in the program were not capable of being ballasted at any depth less than 100 m. In other words, it would either drift at the surface or sit on the bottom of the lake, neither being acceptable for the success of the program. The operation of the drifters was a critical component of the program since the various 'encoded' signals from the sound sources need to be observed in ambient conditions. The presence of a boat with all of its associated electrical and acoustic noise (even with the engines turned oft) reduces the drifter's ability to correctly distinguish the source signal by as much as 30-50%. Since the Lagrangian drifters could not be ballasted to drift at any given depth within the lake, an alternate program was designed using three drifters. Two glass-enclosed drifters were placed at 10 and 30 m on a free-drifting surface-tethered drogue; while the third metal drifter was placed at the surface with its up-linking ARGOS transmitter turned on to provide continuous tracking (monitored via computer back at the lab).

Even though one of the four moored sound sources failed due to a circuitry problem on its power controller board, a great deal of information was never-the-less gathered on the acoustic properties of the lake utilizing the drogued array. Considering the shallow nature of the lake, acoustic propagation distances for tracking underwater drifters was much higher than expected (> 25 kilometers). The primary limitation for tracking was related to acoustic shadow zones "cast" behind islands and shoals. Based on the high correlation of the received signals, the distance over which they were observed, and the primary limitation of acoustic propagation being that of shadow zones, it was determined that a more optimal system would be that of a much lighter, smaller and more economical 1560 Hz system. By moving from the 780 Hz system, sufficient funds were freed up to increase the number of sound source sites from 4 to 6 during the next field season.

The deployment of the six new sound sources (1560 Hz) took place from June 10-12,2002 with Jean Claude Gascard and Tom Manley being co-chief scientists. Pierre Tillier and researchers from NOAA GRERL were also on hand to complete a co-operative program between the RAFOS program and the ongoing Shelburne Bay study. During this program, a total of nine moorings were deployed in the Main Lake From June 13-15, acoustic propagation testing occurred with the release of a similar drogued array used in the first field season.

Since the standard ocean drifters could not be used in any shallow water environment, the creation of the first prototype Lake Champlain Profiler (LCP) proved to be the most time consuming via the modification of a WHOI "SOLO" float. Designed for deep ocean work, the unit was significantly modified for shallow water (lake) use. Since external soft parts (rubber, plastic, and O-rings) compress to

smaller volumes within the first 100 m, they provide nondesirable aspects of uncontrolled buoyancy changes.

The most demanding effort was devoted to the modification of the ballasting software. The code had to be changed to 1) optimally sample its depth more frequently, 2) determine the proper volumetric changes to compensate for being out of its proper depth range, 3) determine a bounding window (above and below the programmed depth) that is considered acceptable and buoyancy corrections would not be made, 4) consider the effects of environmental changes in density (i.e., temperature changes of the water column), 5) consider the response of the unit to rapid environmental changes caused by internal waves, and 6) make sure that the unit does not go into continual oscillatory motion about its preprogrammed depth.

At 1400 on the 3rd of August, the LCP was released for its first un-tethered deployment at the latitude of Burlington in the center of the lake. It was programmed to maintain a depth of 30 m for 16 days, resurface, and then transmit its data to Argos. Once Argos receives the data, a positional fix (+/- 1 km) can be provided to the user. Having only aim thin whip antenna sticking out of the water makes any drifter difficult to locate, however, the use of an Argos beam finder permits directional data to be obtained on the boat within the locale of the initial Argos fix. On August 19th, the first fix by Argos was obtained at WHOI and relayed to the RV Melosira. After plotting the location, the drifter was found to be -22.5 km south of Thompsons Point and 44.2 km south of its initial deployment position. After a great deal of searching, it was eventually retrieved from beneath a dock along a rocky shore some 6 km south of Northwest Bay.

Three additional 1 to 3 day deployments (24-25, 25-28, 28-30 Oct.) were later completed subsequent to the repair of the Argos transmitter in order to further check on the Argos transmitter and to complete the verification process of the internal controller.

In summary of the 2002 field season, the 1560 Hz sound sources operated correctly without any internal failures. The propagation distance of <15 km, rather than the expected 25 km, was due to low power settings. The newer version of the sound sources will have increased power and are expected to achieve the 25 km range needed for Main Lake coverage. Initial problems with the prototype LCP have been solved. The last 3 deployments and successful recoveries of the LCP show that it is fully functional in shallow « 100 m) lake environments.

## Program Objectives

As per last year, the program objectives would be to follow two separate paths, each being dependent on the results of the 2003 RAFOS field. Since the LCP worked well in the lake during the last season, very few modifications are planned for this coming field season. The contingencies for the next field season are, however, dependent on the outcome of the upgrades to the sound sources. If the modified sound sources perform well during the 2003 field season (tracking distances of ~25 km), funds are requested for a fully operational field program in 2004 that will utilize four LCP pro filers. Two will be placed in the epilimnion and two will be placed in the hypolimnion. In each hydrodynamic layer, the two drifters will be placed at opposite sides of the lake at the latitude of Burlington. In other words,

there will be two LCPs on the eastern as well as western sides of the lake. The two drifters will start vertically aligned but in different layers (epilimnion and hypolimnion). In order to accomplish this, funds will be spent on acquiring two additional sound sources and three additional LCPs.

Mike McCormick and Terry Miller (NOAA GLERL) will be involved with the deployment of the RAFOS / VORTICITY WAVE moorings as well as a special surface wave monitoring ADCP to the west of the Burlington breakwater. After the deployment of the subsurface moorings, Mike and Terry will work on a Lagrangian surface motion program through the use of -10 GPS tracked drifters for a period of approximately 2-3 weeks. These observations will closely compliment the LCP motion at depth. Tom Manley will still be co-chief scientist on the various programs (RAFOS / VORTICITY WAVES) as well as responsible for the continued integration and analysis of all of the information collected during the 2004 field season.

## Approach

The future of the RAFOS program no longer rests on the reliability of the LCP prototype, but the newly modified sound sources. If these new sound sources are capable of achieving a propagation distance of 20-25 km, then we will seek to deploy a fully operational array of sound sources and four LCPs to take a first look at the summer circulation within the Main Lake. Funds will be expended to purchase the necessary permanent equipment to support this program. Each of the eight sub--surface sound source moorings will be equipped with either ADCPs and/or temperature sensors that will be utilized to define the internal dynamics and currents within the lake at the time that the Lagrangian drifter program is taking place. If it turns out that the sound sources need further development. Pierre Tillier will provide necessary modifications during the off-season. The array will then be tested in the 2004 field season with as many LCPs that left over funds will permit. Standard products that will be obtained, as part of a full-scale program, will be met data obtained from Colchester Reef and Burlington International Airport (BIA). If a full-scale program can be run in 2004, an analysis program will be undertaken with LOYDC being in charge of reducing the drifter data and Tom Manley being responsible for the reduction and analyses of the moored data sets. Mike McCormick will be responsible for the surface wave mooring as well as the surface drifter program. Dr. Ken Hunkins recently completed initial modeling of vorticity waves in the lake. Included in this proposal (Appendix I) is the subcontract that Ken Hunkins has developed for the continuation of vorticity wave modeling. In short, Dr. Hunkins will primarily concentrate on the dynamic link between the Main Lake and the drifters.

Dynamically, we are at a time where the mean circulation of Lake Champlain should have been well documented. Unfortunately, this has not occurred due to the strong oscillatory motion of the internal seiche and the type of fixed, Eulerian measurements that have been taken. The successful implementation of a Lagrangian tracking method is required to solve this problem. Results from such a combined system of Eulerian and Lagrangian methods will conclusively provide evidence of long-term circulation within the lake as well as the presence of sub-basin scale circulation patterns that have been suggested from previous numerical modeling studies on the lake. Such a system would also be sued to provide information on

circulation patterns during non-stratified (winter) conditions. These results most definitely provide a high degree of significance to this program in that it will be these observations that will eventually be used to confirm sediment distribution patterns as well as numerical models that will be used to make management decisions in the lake.

## CA4/II-05: Atmospheric Mercury Deposition in Vermont – Sources and Long-Term Trends

*Principal Investigators: Deane Wang, University of Vermont and Gerald Keeler, University of Michigan*

NOAA Strategic Goal 1

The primary objectives of this proposed research are to complete analysis of collected event-based precipitation and vapor phase samples to bring the historical record up to date; continue year-round monitoring of atmospheric mercury deposition in wet deposition and particulate phase in the Lake Champlain Basin; investigate the long-term trends in mercury deposition over the past decade; and, determine the major sources and atmospheric transport pathways for mercury deposition in Vermont.

The study is part of an integrated program of research and monitoring of atmospheric deposition in the Lake Champlain Basin coordinated with NOAA, the Vermont Monitoring Cooperative, and the lake Champlain Research Consortium. The project investigators are actively collaborating with several major regional mercury research initiatives such as the USEPA Northeastern Region REMAP Mercury Study, and the USDA Forest Service supported Northeast Ecosystem Research Cooperative International Mercury Working Group. The long-term characterization of mercury deposition provides the backbone for all of the mercury cycling research in the basin including future work looking at dry deposition to forested ecosystems, re-emission from soils and plant canopies, storage and release from terrestrial ecosystems in Vermont. The long-term data should provide insights into how mercury levels and deposition have responded to regional and national reductions in atmospheric mercury emissions over the past decade.

The University of Michigan Air Quality Laboratory, in collaboration with the University of Vermont, and the Vermont Monitoring Cooperative, initiated atmospheric mercury and mercury cycling research at the Proctor Maple Research Center in Underhill, Vermont in 1992. Sponsored by EPA and NOAA, the station embarked on an event-based sampling program for mercury in wet precipitation. Collecting rain and snowfall storm by storm, rather than on a weekly sampling schedule, allows one to relate the mercury concentration patterns in individual storms to air mass history using back trajectories. In this way, geographic sources of atmospheric mercury emissions are identifiable. In addition, trace element analysis of the event samples provides the tracers that can be used to apportion the mercury to its sources, e.g., incinerators, coal combustion, etc. The Proctor site has the longest continuous running event-based mercury wet-deposition station in the world.

Over the past decade the atmospheric sampling has continued and this work was integrated into ecosystem cycling studies looking at snow melt, stream export, forest cycling including throughfall and litterfall flux measurements. Because of the

quality, high temporal-resolution data and location in the Lake Champlain basin, estimates of atmospheric mercury deposition derived from the measurements at Underhill have been and are being used by more than a dozen scientists investigating mercury in terrestrial and aquatic environments. These programs have fostered a community of researchers including atmospheric scientists, hydrologists, limnologists, ecologists, and biogeochemists who actively collaborate on the study of the impact of mercury on the Vermont's and New England's ecosystems.

This consortium of researchers has worked to identify critical areas for advancing our understanding of the mercury exchanges between ecosystems and the atmosphere, the redistribution of mercury in the landscape, and the transfer of atmospherically deposited mercury to biota. The group focused on formulating research questions that would provide substantial new insights in a short period of time and that would provide information useful for the assessment of mercury risks and impacts throughout the Northeastern USA. The priority tasks are presented below and constitute the primary objectives of the proposed research.

## Objectives/Project Tasks

- Fill-in the long-term event precipitation record at Underhill, VT by completion of the analysis of archived samples for mercury concentration.
- Construct a QA'd database of the historical event-based precipitation and ambient total gaseous and particulate phase mercury.
- Calculate and assemble a consistent meteorological database for the entire period of record.
- Investigate the temporal and seasonal trends in mercury concentration and deposition at the Procter site.
- Investigate the sources and transport of mercury observed at the Vermont site.
- Facilitate inter-laboratory exchanges and extend the long-term record of mercury concentration in precipitation and in air at Underhill, VT.

## CA4/II-06: Monitoring Meteorological Conditions on Lake Champlain – Support for the Colchester Reef Meteorological Station

*Principal Investigators: Deane Wang, University of Vermont; Richard Furbush, University of Vermont; and Carl Waite, University of Vermont*

NOAA Strategic Goal 2

## Introduction

Since July 1996 the Vermont Monitoring Cooperative (VMC) has operated and maintained an automated meteorological station on the navigational light tower at Colchester Reef, to provide near real-time meteorological data for Lake Champlain to researchers, resource managers and the public. This effort has been supported by contributions from the Lake Champlain Research Consortium (LCRC), the VMC, UVM's School of Natural Resources (SNR), and the National Weather Service (NWS). Data from this station are widely accessed to support NOAA atmospheric and hydrodynamic modeling efforts, other environmental and ecological research,

local and regional weather forecasting, and commercial and recreational users of Lake Champlain.

The meteorological station at Colchester Reef is important to a wide variety and increasing number of users in the Lake Champlain region. The LCRC identified the need for this station as a research priority under atmospheric processes (December, 1999). In addition, on-lake meteorology was identified as an important research and monitoring priority by the Lake Champlain Management Conference (Watzin 1992). Finally, as indicated in the LCRC research priorities, these data are also one of the NWS' s most popular and are considered invaluable for prediction purposes by the NWS (see attached letter of support (2000) from the NWS).

Meteorological data from this station are important for both atmospheric and hydrodynamic modeling efforts in the Lake Champlain Basin. Specific research programs, among many, that benefit directly from this station are Lake Hydrodynamics (T. Manley, Middlebury College), Mesoscale Modeling of Pollutant Deposition (Scherbatskoy et al. 1999), A Mass Balance Assessment for Mercury in Lake Champlain (Goa et al. 2003), and fisheries ecology (D. Parrish, USGS, VT Cooperative Fish and Wildlife Research Unit, UVM). These projects require continuous, accurate, data on lake wind fields, temperature, and solar radiation to use in their respective models. Some projects require real-time or near real-time data to facilitate field activities. This meteorological station provides data not previously available on the magnitude and direction of wind, and on daily and seasonal variation in temperature and solar radiation that help understand and predict water currents and the behavior of the internal seiche in Lake Champlain. These data also represent conditions on the Lake itself and in the lower atmospheric boundary layer over the Lake that are critical to modeling the behavior of the atmosphere in the region. This information enhances the resolution by a factor of 10 of models of pollutant movement and deposition in the Lake Champlain Basin. Overall, numerous research projects benefit from these data supporting efforts by NOAA, the VMC, UVM, Middlebury College, SUNY Plattsburgh, St Lawrence University, VT DEC and NY DEC.

The near real-time (1 hour lag) meteorological data from Colchester Reef have proven to be of great value to NWS for local and regional forecasting, lake wind and wave advisories, and public service efforts. The near real-time data are widely accessed through the NWS, the VMC, and the Burlington Environmental Monitoring for Public Access and Community Tracking (EMP ACT) program.

## Objectives

- To insure continuous operation of the meteorological station at Colchester Reef.
- To provide and archive continuous, high quality, near real-time, meteorological data from Lake Champlain.
- To summarize annual and inter-annual meteorological trends in these data.

## Methods

In July 1996 this meteorological station was established with the cooperation of the US Coast Guard station in Burlington, on the navigational light tower at Colchester

Reef. This station provides automated monitoring of wind speed and direction, air temperature, relative humidity, barometric pressure, and total solar irradiance. Currently, neither water temperature nor precipitation data are being recorded, but instrumentation will be procured and installed as funding becomes available.

### Data Distribution

Sensors are interrogated once each minute, but data is stored and archived as a 15 minute average beginning on the even hour (four records/hour). Data are downloaded hourly by a data radio link to a VMC server in Burlington where the data are archived and made available to the NWS and others. The NWS provides hourly and past 24 hour, continually updated, summaries of the 15 minute average data on the World Wide Web at: http://www.nws.noaa.gov/er/btv/data/reefdata.txt. The data are also available through the Burlington EMPACT web site: http://BurlingtonEcolnfo.net. Archived meteorological data from this station are available on the VMC web site at: httIr/lvmc.uvm.edu.

### Results Expected and Their Significance

It is expected that this meteorological station will continue to provide high quality, continuous, near real-time, meteorological data to the public. These data are and will continue to be important to research on atmospheric processes, lake hydrodynamics, and ecological processes. The NWS will continue to use these data to enhance their predictions and lake advisories, by ascertaining actual weather conditions on Lake Champlain. Commercial and recreational boaters, other recreational users, and interested individuals or groups, including students, will continue to have access to these data directly through the internet at the NWS and Burlington EMP ACT web sites (for near real-time data) or the VMC web site (for archived data).

An annual report will be prepared by the VMC to summarize the year's meteorological data and information about site operations. This will include statistical summaries of all weather parameters and an assessment of long-term climatic patterns and trends for this station. This report will be provided annually to the LCRC and the VMC.

## CA4/II-07: Monitoring Meteorological Conditions on Southern Lake Champlain – Establishment and Operation of a New Meteorological Station at Diamond Island

*Principal Investigators: Deane Wang, University of Vermont; Richard Furbush, University of Vermont; and Carl Waite, University of Vermont*

NOAA Strategic Goal 2

Lake Champlain, as the surrounding landscape, is not uniform. Differences in lake geometry, underwater topography, geophysics, and influences of the surrounding landscape affect meteorology at or near the water surface. In the same way a single meteorological station is not sufficient to characterize all of Vermont, a single station also is not representative of the entire Lake. The need for an on-lake meteorological station located near the southern end of Lake Champlain has been expressed for some time. Diamond Island, located near the mouth of Otter Creek in Ferrisburg,

VT, has emerged as one possible location for a southern lake meteorological station, although, other locations should be explored. Like Colchester Reef, Diamond Island has an existing US Coast Guard-maintained tower with navigational light, which would aid in establishment of a new meteorological station at that site.

Meteorological data from Lake Champlain are important to a wide variety and increasing number of users in the Lake Champlain region. The LCRC identified the need for the Colchester Reef meteorological station as a research priority (December, 1999) and now supports the establishment of a second on-lake station on southern Lake Champlain. The idea for a new southern Lake meteorological station was further endorsed by scientists at a recent Atmospheric Deposition workshop held in Burlington, VT on June 5-6,2003. In addition, on-lake meteorology was identified as an important research and monitoring priority by the Lake Champlain Management Conference (Watzin 1992). The LCRC priorities indicate Colchester Reef data are also one of the NWS's most popular and are considered invaluable for prediction purposes by the NWS. We anticipate the meteorological data from southern Lake Champlain will be equally valuable and popular and will allow more accurate characterization of meteorological conditions across Lake Champlain. The NWS has stated that a meteorological station on southern Lake Champlain would provide greater spatial resolution necessary for more accurate weather warnings. These data would also potentially improve modeling and forecasting of weather conditions over water surfaces and land areas at 5 km or greater resolution (see attached letter of support from the NWS).

On-lake meteorological data are important for both atmospheric and hydrodynamic modeling efforts in the Lake Champlain Basin. Specific research programs, among many, that benefit directly from Lake Champlain meteorology are Lake Hydrodynamics (T. Manley, Middlebury College), Mesoscale Modeling of Pollutant Deposition (Scherbatskoy et al. 1999), A Mass Balance Assessment for Mercury in Lake Champlain (Goa et at. 2003), and fisheries ecology (D. Parrish, USGS, VT Cooperative Fish and Wildlife Research Unit, UVM). These projects require continuous, accurate, data on lake wind fields, temperature, and solar radiation to use in their respective models. Several projects require real-time or near real-time data to facilitate field activities. These lake meteorological stations (Colchester Reef & proposed south lake) provide data not previously available on the magnitude and direction of wind, and on daily and seasonal variation in temperature and solar radiation that help understand and predict water currents and the behavior of the internal seiche in Lake Champlain. These data also represent conditions on the Lake itself and in the lower atmospheric boundary layer over the Lake that are critical to modeling the behavior of the atmosphere in the region. This information enhances the resolution by a factor of 10 of models of pollutant movement and deposition in the Lake Champlain Basin. Overall, numerous research projects benefit from these data supporting efforts by NOAA, the VMC, UVM, Middlebury College, SUNY Plattsburgh, St Lawrence University, VT DEC and NY DEC.

## Objectives

- To establish an automated meteorological station at Diamond Island (or other appropriate southern Lake Champlain site).

- To insure continuous operation of this southern Lake Champlain meteorological station.
- To provide and archive continuous, high quality, near real-time, meteorological data from Lake Champlain.
- To summarize annual meteorological trends and comparisons with Colchester Reef data.

## Methods

In January 2004 equipment will be purchased to establish an automated meteorological station on Diamond Island (or other appropriate site) with instrumentation comparable to that at Colchester Reef. Instrumentation will be installed and this southern Lake Champlain meteorological station established in May/June 2004. This station will provide near real-time meteorological variables including wind speed and direction, air temperature, relative humidity, barometric pressure, total solar irradiance, precipitation (non-freezing months) and water temperature.

The station will consist of a Campbell Scientific Inc. CRlOX datalogger housed in a weatherproof box. Power will be provided with 12v deep cycle marine batteries charged with a 64 watt solar panel. Data will be automatically downloaded via a cell phone link from the CRlOX datalogger to a base station located in the Rubenstein Ecosystem Science Lab at UVM.

A list of variables measured include air temperature, relative humidity, barometric pressure, wind speed, wind direction, total radiation, precipitation, and water temperature.

## Data Distribution

Sensors will be interrogated once each minute, but data will be stored and archived as 15 minute averages beginning on the even hour (four records/hour). Data will be downloaded hourly by a cell phone link to a VMC server in Burlington, where the data will be archived and made available to the NWS and others. It is expected that the NWS will provide hourly and past 24 hour, continually updated, summaries of the 15 minute average data on the World Wide Web at: http://www.srh.noaa.gov. Near real-time data will also be available through the Burlington EMP ACT web site at: http://BurlingtonEcoInfo.net. Archived meteorological data from this station will be available on the VMC web site at: http://vmc.uvm.edu.

## Results Expected and Their Significance

It is expected that this meteorological station will provide high quality, continuous, near real-time, meteorological data to researchers, the NWS, and the public. These data will be important to research on atmospheric and ecological processes, and lake hydrodynamics. The NWS will use these data to enhance their predictions and lake advisories, by ascertaining actual weather conditions on Lake Champlain. Commercial and recreational boaters, other recreational users, and interested individuals or groups, including students, will have access to these data directly

through the internet at the NWS and Burlington EMP ACT web sites (for near real-time data) or the VMC web site (for archived data).

An annual report will be prepared by the VMC to summarize the year's meteorological data, information about site operations, and will include a comparison with data from Colchester Reef. Statistical summaries of all weather parameters for this station will be presented. This report will be provided annually to the LCRC and the VMC.

## CA4/II-08: Investigation on Sources and Sinks for Mercury in Lake Champlain

*Principal Investigators: Ning Gao, St. Lawrence University; Philip K. Hopke, Clarkson University; Richard Poirot, Vermont Agency of Natural Resources; and, Neil Kamman, Vermont Agency of Natural Resources*

NOAA Strategic Goal 1

### Introduction

Thus far, using the grants from the LCRC and CILER, we have created a mercury mass balance model for the Lake Champlain, performed three types of source-receptor modeling analysis to identify the sources of Hg deposition to the basin, and water sampling and sediment coring are underway. The modeling efforts are based on analysis of nearly a decade of quality data on atmospheric deposition of mercury (both wet and dry) from the Proctor Maple Atmospheric Station in Underhill, Vermont near the center of the basin, some historic data on streamflow Hg fluxes in basin streams, and a modest new data collection effort for Hg concentrations in the major inlet streams to Lake Champlain, its outlet, and the lake itself. The source-receptor modeling effort has revealed some significant correlations between Hg in Lake Champlain and certain types of emission sources and provided valuable source apportionment information on Hg. The mass balance model has provided evaluation on the importance of different input pathways to the lake, identified some data gaps that will soon be filled in by funded sampling work and hopefully by more future funding as well. A user interface has been created for the STELLA model so the modeling outputs could be displayed simultaneously and geographically for different lake segments. It could be used to model the effects of seasonal variation and annual fluctuation in various inputs and outputs. Currently the project is in full swing with source-receptor modeling in the verification phase, the mass balance model is still being refined and the important summer sampling in progress (see below).

### Objectives

We propose to build on this initial success and request funding to expand the project in several ways.

- Refine the mass balance model to include more detailed methylmercury speciation so its potential effect on bioaccumulation could be studied.
- Refine the mass balance model to include more accurate sedimentation process in the model. Not only will it help to gain a better understanding of

mercury sedimentation and re-suspension processes in Lake Champlain, the sediment Hg flux record derived will also help to restore the historical patterns of regional and continental atmospheric emission and deposition.

- Enhance the STELLA mass model's graphic capabilities by exploring the possibility of a GIS linkage.
- Expand the regions for source-receptor modeling to uncover relevant emission sources, especially the ones located outside of the current studied region that are significant contributors of Hg to Lake Champlain via long-range transport.
- Refine the source-receptor modeling analysis to increase the accuracy for source apportionment.
- Expand the target period for source-receptor modeling to uncover any newer emission sources and any changes in the patterns of emission sources.

## Research Findings

We have further refined a working mercury mass balance model for Lake Champlain that was constructed using the STELLA software at St. Lawrence University. The model has incorporated such physical pathways as atmospheric deposition, tributary input, revolatilization (out-gassing), dispersion, and advection. We have also made some progress linking the STELLA model to ArcView, a GIS software to expand the model's graphic capability.

Sediment coring and analysis for total mercury and lead-dating have been completed at DEC-Vermont for three sites in the lake mercury sedimentation flux. The work is underway to obtain the lakebed areas for the respective bays. Once we have that information, we will incorporate sedimentation component into our mass balance model.

## Publications

Gao, N., N.G. Armatas, B. Puchalski, P.K. Hopke and R. Poirot. 2004. A preliminary investigation into the possible emission sources for atmospheric mercury found in the Lake Champlain basin. In Lake Champlain: Partnerships and Research in the New Millennium, T.O. Manley, P.L. Manley, and T.B. Mihuc, eds. Kluwer Academic/Plenum Publishing, New York. Pp. 21-38.

Gao, N., N.G. Armatas, S. Drake, C. Cady, B. Olsen, J. Hanley, N. Kamman, G. Keeler, T. Scherbatskoy, T. Holsen, L. McIlroy. 2004. A mass balance assessment for mercury in Lake Champlain. *Environ Sci & Technol* (submitted).

## Presentations

Lafferty, K. and N. Gao. 2004. Identification of sources of fine particulate air pollutants in the Lake Champlain basin using positive matrix factorization (PMF) analysis. Lake Champlain Research Consortium Student Conference. April 24. Middlebury College, Burlington, Vermont.

Krumhansl, K. and N. Gao. Identification of sources of mercury pollution in the lake Champlain basin using potential source contribution function (PSCF) analysis. Lake Champlain Research Consortium Student Conference. April 24. Middlebury College, Burlington, Vermont.

## Significant Interactions

Since this is a multidisciplinary and multi-institutional project, there has been a lot of interaction among the investigators at St. Lawrence University, Clarkson University, and DEC-Vermont. We have also maintained close contact with USGS-Vermont, the Lake Champlain Research Consortium, and the NOAA/Air Resource Laboratory. We also used opportunities to reach the general public through other organizations such as the Vermont Monitoring Cooperative, the Adirondack Research Consortium, and the St. Lawrence County Environmental Management Council.

## Additional Funding

Additional funds in the amount of $15,000 were provided to Ning Gao by the Air Quality Control Division, DEC-Vermont (9/1/03-8/31/04).

## Student Participation

Several undergraduate students participated in this project (no thesis required for chemistry major).

Nathan Gabrial Armatas, BS in chemistry, May 2002. St. Lawrence University. Nathan is now a PhD student in chemistry at Syracuse University.

Benjamin Puchalski, BA in environmental studies/government, May 2003. St. Lawrence University. Ben is now a realty agent in Maryland.

Melissa Rury, BS in chemistry, May 2003. St. Lawrence University. Melissa is now a PhD student in chemistry at the University of Maryland at College Park.

# COASTAL AND NEARSHORE PROCESSES

CILER research in coastal and nearshore processes has focused on both the marine and limnetic nearshore environments. CILER projects have studied coastal processes in the Great Lakes, Gulf of Mexico, South Atlantic Bight, and the northeastern coast of the United States. A particular emphasis has been the investigation of exchanges of materials from tributaries into the nearshore zone. Those investigations have covered a wide variety of disciplines including physical, chemical, and biological oceanography and limnology, and in many cases have combined all three fields. This variety of research is viewed as a major strength for CILER since a comparison among different coastal environments provides unique opportunities for insight into ecosystem structure and function.

## CA4/III-02: DEVELOPMENT AND CALIBRATION OF SEDIMENT TRANSPORT MODEL AND SPECTRAL WAVE-CURRENT BOUNDARY LAYER MODEL WITH IN SITU MEASUREMENT DATA

*Principal Investigator: David Schwab, Great Lakes Environmental Research Laboratory*

NOAA Strategic Goal 1

### Introduction

The Episodic Events-Great Lakes Experiment (EEGLE) was undertaken to investigate the episodic sediment resuspension (or entrainment) events in the Southern area of Lake Michigan. The integrated hydrodynamic, wind-wave, and sediment transport model has been used to simulate the largest events of record in March 1998. The simulation results showed very similar patterns with the observed satellite image but missed some detailed features in magnitude and spatial distribution of resuspended sediment concentration. It is believed that the missing features may be attributed to several possible reasons including: (1) overestimation or underestimation of bottom shear stress induced by wave-current interaction; (2) spatial variation and error in critical shear stress and erosion rate estimation of bottom sediment; (3) different particle size distribution and flocculation effect; (4) non-uniform distribution of vertical sediment concentration profile; and (5) inaccuracies in the wave prediction model. To improve simulation results, a more accurate representation of bed shear stress induced by wave-current interaction in the hydrodynamic module and of sediment erodibility (critical shear stress and erosion rate) in the sediment module is of critical importance among these reasons.

Several wave-current bottom boundary layer models have been developed and implanted into hydrodynamic model to produce the input data (bottom shear stress) for sediment entrainment model. Those models calculate the total combined bed shear stress as the vector sum of wave and current induced terms, that are estimated individually from the mean bottom current and the maximum near bottom orbital velocity calculated from linear wave theory. There exists some high uncertainty in estimation of combined friction coefficient in the above semi-empirical models, resulting in high uncertainty of bed shear stress calculation. Since the coefficient was usually obtained from an empirical model expressed by single

wave component that depended on bed roughness or was calibrated from laboratory data, it cannot represent well the irregular waves and currents in the field and their non-linear interaction. To date the best way to better estimate the bed shear stress caused by irregular waves and current is to calibrate the wave-current boundary layer model with in-situ measurements.

Another key issue in cohesive sediment transport modeling is estimating the critical shear stress and erosion rate of bottom sediment that is significantly variable over horizontal bed surface and vertical sediment depth. Both are site specific variables depending on the sediment properties such as bulk density, particle size distribution, organic contents, total salt concentration and so on. To date, the most reliable way to estimate them is direct measurement in the field.

## Objectives

The objectives of this research are focused on the development/implementation of new spectral wave-current boundary layer model and cohesive sediment resuspension model, and their calibration with in-situ measurement data. Thus, this research will be performed in two phases: (1) simultaneous measurements of flow field and sediment resuspension rate, and (2) development (or implementation of existing model) and calibration of spectral wave-current model and sediment resuspension model using in-situ measurement data. These objectives address key scientific areas under CILER's Task III research theme of coastal and nearshore processes.

## General Approach

The proposed in-situ measurement system will consist of a new up-looking wave-measuring acoustic Doppler current profiler (ADCP) to measure directly two spectrums (energy spectrum and directional spectrum) of irregular waves and the current profile, and optical back-scattering sensors to measure sediment concentration. Two in-situ measurement systems were deployed at 10 m and 20 m water depths off of St. Joseph, MI in fall of 2002 as a part of EEGLE Project 5 by collaboration with Great Lakes Environment Research Laboratory (GLERL).

Since simple boundary layer models for monochromatic wave are commonly available, the model will be extended to consider the effect of irregular wave and water stratification. Wave and current field data measured by ADCP and ADV will be analyzed to obtain the individual components of shear stress (wave and current component) separately, using four different methods: covariance method, turbulent kinetic energy method, logarithmic profile method, and energy dissipation method. The calculated bed shear stresses from the model will be calibrated with that from the in-situ measurement data.

## Expected Products and Benefits

This in-situ measurement technique is a new and unique method to estimate cohesive sediment erosion rate directly in natural flow condition. The hydro-dynamic and sediment transport model can be calibrated more reliably with unique in-situ measurement data. This calibrated model may explain the detailed features

of sediment resuspension in Lake Michigan. In addition, government agencies and private firms involved with sediment clean up and navigational channel maintenance will be benefit from this research.

## Accomplishments

Work was completed on the deployment, retrieval, and data analysis for the Lake Michigan October 2002 field program. Considerable progress has been made on a manuscript for the 1-d and 2-d sediment dynamics model. Models have been calibrated using EEGLE sediment and transport data sets.

## Publications

Lee, C., D.J. Schwab and N. Hawley. 2004. Sensitivity analysis of sediment resuspension parameters in coastal area of southern Lake Michigan. *J. Geophys. Res.* (in press).

## CA4/III-03: RAFOS AND SHELBURNE BAY PROGRAM

*Principal Investigator: Thomas O. Manley, Middlebury College*

NOAA Strategic Goal 1

Shelburne Bay still remains an enigma with respect to its internal dynamics. While it does occasionally exhibit internal seiche oscillations at a period associated with that of the Main Lake (~ four days), it also exhibits a rather consistent diurnal (24 hour) period. Observations of both surface and deep currents have shown that the diurnal internal seiche period cannot be internal to Shelburne Bay. In order to account for bimodal circulation patterns set up within Shelburne Bay, the node (assuming uninodal structure) must be located to the north of Shelburne Bay and most likely in Burlington Bay. Two hypotheses have been proposed for the origin of the diurnal internal seiche within Shelburne Bay. First, it is created as part of a larger combined Burlington and Shelburne Bays system with the standing wave primarily aligned in a north-south direction. The second one requires a cross-lake internal mode existing from Willsboro Point to Shelburne Bay.

A specialized mooring array was deployed in early June 2002 to specifically look for the presence of both internal and surface cross-lake modes and was recovered in late August 2002. Analyses of these data are ongoing and will support other collaborative efforts in Lake Champlain. For example, Ken Hunkins, using pressure sensors located inside as well as outside Shelburne Bay, found two dominant surface seiche periods; one at four days that corresponds with the Main Lake baroclinic mode and a much smaller amplitude wave with a period of approximately 35 minutes. While observed in many lakes, a barotropic (surface) mode can be forced by an underlying baroclinic mode, however, both can be observed at the same location. In Shelburne Bay, often the internal Main Lake mode is missing while the surface mode is present. Also of note is the fact that the surface barotropic mode from the Main Lake is an order of magnitude larger than the 35-minute period surface standing wave believed to be associated with Shelburne Bay itself. Hodographs of ADCP data (Sardilli, 1999) show that there appears to be net

advective motion into and out of the Shelburne Bay but is dependent on the winds as well as the chosen layer (i.e., epilimnion or hypolimnion). One major outcome to this program was the creation of a new bottom bathymetry map for Shelburne Bay. A student at Middlebury College was working on the analysis of several other aspects of data taken within Shelburne Bay for a senior thesis, but then later dropped the project due to an overload in classes and student teaching.

## Publications

Manley, P.L., T.O. Manley, M.C. Watzin and J. Gutierrez. 2002. Lakebed pockmarks in Burlington Bay, Lake Champlain: I. Hydrodynamics and implication of origin. This paper utilized some of the Shelburne Bay data collected during the 1999 field season. Submitted to the Lake Champlain Research Consortium Monograph.

Sardilli, D. 1999. The internal dynamics of Shelburne Bay. Senior thesis of Middlebury College, Department of Geology, 62 pp.

Gutierrez, Joshua. 1999. The general pockmark in Burlington Bay, Lake Champlain. Undergraduate thesis of Middlebury College, Department of Geology. 63 pp.

Barsotti, M.G., R. Pratt, J. Faye, T.O. Manley and M. Samadpour. 1999. Surface water source characterization to overcome operational complacency and aid source delineation. Proceedings of the 1999 Water Quality Technology Conference. Tampa, Florida.

## Presentations

All senior thesis students gave presentations at the Vermont Geological Society and the Lake Champlain Research Consortium Student Symposium, both being held in the early spring of their graduating year.

Manley, T.O., P. Tillier and J.C. Gascard. 2002. Acoustically-tracked neutrally-buoyant Lagrangian drifters in Lake Champlain – a feasibility study. Ocean Sciences Meeting. February 11-15. Honolulu, Hawaii.

Barsotti, M.G., R. Pratt, J. Faye, T.O. Manley and M. Samadpour. 1999. Surface water source characterization to overcome operational complacency and aid source delineation. Proceedings of the 1999 Water Quality Technology Conference. Tampa, Florida.

Manley, T.O., J.C. Gascard and P. Tillier. 1998. Acoustically tracked Lagrangian drifters in Lake Champlain. June 9-14. Green Bay, Wisconsin.

## Significant Interactions

We have had significant interactions with the Champlain Water District (CWD) which initially funded the pilot program that later developed into the research program that has evolved to date. The water quality personnel are extremely interested in the results that come from this work in that it will eventually lead to better methods to obtain the cleanest water from Shelburne Bay. A better understanding of the dynamics operating in the Bay will, in turn, lead to better

efficiency in the treatment and handling of raw lake water. They are also now developing plans to install a second water intake pipe onto their existing system. The hydrodynamics of the Bay will play an important part in the positioning of the second intake pipe. Interactions with NOAA and Middlebury College are very strong and we are continually working on the further analysis of the data. There has also been some interest by the biological community as to the location of specific planktonic species (within Shelburne Bay) in relation to the thermocline as well as the vertical migration of some species. Vertical migration was first observed in the ADCP data using backscattering.

## Additional Funding

New funding was just received to continue work on the RAFOS and Shelburne Bay experiments. This funding was through the Lake Champlain Research Consortium and NOAA.

## Student Participation

Sardili, D. The internal dynamics of Shelburne Bay, a senior thesis of Middlebury College, Department of Geology. 62 pp.

Dana Chapin was to complete another large section of data analysis from the Shelburne Bay data set but had to drop the thesis program mid-year after she realized that her student teaching, sports, and classes were too much to cope with.

## LARGE-LAKE ECOSYSTEM STRUCTURE AND FUNCTION

In the past few decades, environmental scientists have become increasingly aware of the interwoven relationships between ecosystems and their components. Research that subscribes to this concept has been broadly defined as the "ecosystem approach." A salient aspect of limnology and the ecosystem approach is the recognition that critical materials cycle extensively through all components and trophic levels of the aquatic environment as well as between lakes, the overlying atmosphere, and adjacent land masses. Ecosystem studies of large lakes strive to examine not only the flora and fauna but also the physical and chemical environment and exchanges between land, water, and air. CILER research projects within this task, that embrace the ecosystem approach, are conducted by a cohort of physical, chemical, and biological scientists, similar to the projects in climate and large-lake dynamics and in coastal and nearshore processes. The primary distinction between large-lake ecosystem structure and function projects and other CILER projects is that the former are more focused on a specific aspect of large-lake structure and function.

### CA4/IV-01: *CERCOPAGIS PENGOI*, A NEW INVADER OF LAKE MICHIGAN: FOOD WEB INTERACTIONS AND COMPETITION WITH *BYTHOTREPHES*

*Co-Principal Investigators: Henry A. Vanderploeg, Great Lakes Environmental Research Laboratory and Radka Pichlova, University of Michigan*

NOAA Strategic Goal 1

The main objective of the proposed research was to clarify the feeding biology and role of a new invader of Lake Michigan, *Cercopagis pengoi*, in a plankton food web. *Cercopagis* shares many traits in common with *Bythotrephes*, another nonindigenous predatory cladoceran that invaded the Great Lakes basin earlier and caused serious changes. Therefore, the competitive and/or predatory relations between *Cercopagis* and *Bythotrephes* will be investigated as well.

Field collections of zooplankton were made and preliminary analysis of population dynamics of *Cercopagis* suggested that *Cercopagis* has a high birth rate in all instars and it can be a significant component of the nearshore zooplankton community.

A major stumbling block to doing experimental work with *Cercopagis* — as reported by our colleagues from Russia, Baltic countries, and North America — has been the high mortality observed in collection, handling, and doing experimental work with this species. Much of our effort was focused on developing methods to collect, handle, and set up experiments without injuring the delicate *Cercopagis*. This required special collection techniques involving large cod-end reservoirs that have been used by oceanographers to aid collection of delicate zooplankton. *Cercopagis* also presents the further difficulty that its hooked and "sticky" tail spine causes the animals to stick together when collected or put in the same container. Thus, it is necessary to isolate individuals immediately after collection. By using these techniques and feeding the animals we have been able to keep them in the lab for

about a week, and we expect to further refine our techniques during the upcoming season. Thus, we believe, it is feasible to do experimental work with *Cercopagis* using careful collection and handling techniques and special but intensive care to keep them alive and healthy in the lab.

Examination of these preliminary data suggests that *Cercopagis* and *Bythotrephes* are competitors and that *Bythotrephes* preys on *Cercopagis*. We hypothesize that *Cercopagis* distribution and impacts are restricted to the drowned river mouth and nearshore region because of predation from *Bythotrephes*, which in turn may be controlled by adult alewives. Alewives and *Bythotrephes* probably structure the plankton at middle depths and offshore waters, respectively. Comparison of depth distributions of *Cercopagis* and *Bythotrephes* at a 45-m deep site during the day indicted that *Cercopagis* was found in the epilimnion, and *Bythotrephes* was found in the metalimnion. This may imply *Cercopagis* is affecting zooplankton in the epilimnion and *Bythotrephes* in the metalimnion. We have not examined nighttime distributions.

Progress for 2004 consisted of a number of experiments with *Cercopagis* and *Bythotrephes* as predators confined in bottles with prey from Lake Michigan. Experiments showed that preferred prey of *Cercopagis* were nauplii, zebra mussel larvae, and Bosmina. Experiments where *Bythotrephes* was given a choice of *Daphnia* and *Cercopagis* as prey indicated that *Cercopagis* is preyed upon at the same rate as *Daphnia*. Known to be a favored prey of *Bythorephes*. These experiments and model studies using field data collected from Lake Michigan suggest that spatial distribution of *Cercopagis* is regulated by *Bythotrephes* predation.

## Publications

Pothoven, S.A. and H.A. Vanderploeg. 2004. Prey selection and diet of alewife in Lake Michigan: seasonal, spatial, and interannual patterns. 2004. *Trans. Amer. Fish Soc.* (in press).

Pothoven, S.A., G.L. Fahnenstiel and H.A. Vanderploeg. 2003. Population characteristics of *Bythotrephes* in Lake Michigan. *Journal of Great Lakes Research* 29(1): 145-156.

Vanderploeg, H.A., T.F. Nalepa, D.J. Jude, E.L. Mills, K.T. Holeck, J.R. Liebig, I.A. Grigorovich and H. Ojaveer. 2002. Dispersal and ecological impacts of Ponto-Caspian species in the Great Lakes. *Can. J. Fish. Aquat. Sci.* 59:1209-1228.

## Presentations

Pichlova, R. and H.A. Vanderploeg. 2003. *Cercopagis pengoi* and *Bythotrephes longimanus* in Lake Michigan. Lake Michigan: State of the Lake Conference. October 21-22. Muskegon, Michigan.

Cavaletto, J.F., H.A. Vanderploeg, M.A. Agy, G.S. Carter, R. Pichlova and S.A. Pothoven. 2003. Seasonal and annual changes in the mesozooplankton community of southern Lake Michigan. The 46th Conference on Great Lakes Research, International Association for Great Lakes Research and International Lake Environment Committee. June 22-26. Chicago, Illinois.

Vanderploeg, H.A., R. Pichlova, S.A. Pothoven, J.F. Cavaletto, G.S. Carter, D.M. Mason, T.O. Hook and E.S. Rutherford. 2003. Finding a niche in the Great Lakes: the emerging *Cercopagis* story. The 46th Conference on Great Lakes Research, International Association for Great Lakes Research and International Lake Environment Committee. June 22-26. Chicago, Illinois.

Pichlova, R., H.A. Vanderploeg, J.F. Cavaletto, and L. Stara. 2003. *Cercopagis pengoi* after three years since invasion to Lake Michigan: changes of population and impact on the food web. ASLO Aquatic Sciences Meeting. February 8-14. Salt Lake City, Utah.

Pichlova, R. and H.A. Vanderploeg. 2002. Predatory interactions by *Cercopagis pengoi*, a new invader to the Great Lakes. ASLO 2002 Summer Meeting. June 10-14. Victoria, British Columbia, Canada.

## CA4/IV-02: An Effects-Based Approach to Screen for Potential Hazard of Bioaccumulated Contaminants

*Principal Investigator: Peter F. Landrum, Great Lakes Environmental Research Laboratory*

NOAA Strategic Goal 1

### Summary

This project continues work begun under CILER's cooperative agreement NA67RJ0148 to investigate the challenge approach to evaluate the hazard represented by bioaccumulated contaminants. Furthermore, the study approach for this year followed on the success of last year with the demonstration, that for *Hyalella azteca,* pyrene and pentachlorobenzene (PCBZ) exhibited additive toxicity on a toxic unit basis. Thus, a challenge exposure was devised with pyrene dosed to the sediment and the PCBZ added in the overlying water to determine whether the challenge chemical could be applied in the aqueous phase. Two experimental designs were used including exposure to no light or to yellow light. These two light regimes were used to prevent photoinduced toxicity. The experiment with yellow light failed because there was an absence of bioaccumulated pyrene in the *H. azteca*. Thus, the toxicity required as expected with no accumulated pyrene was essentially the same body residues as had been required in PCBZ only exposures. Based on past work with fluoranthene, the use of white light should not cause photoinduced toxicity because the organisms should be buried in the sediment during the light phase. Thus, a third design using white light to force the *H. azteca* into the sediment was employed and showed a strong toxicity response. The total number of toxic units required for 50 percent mortality was 1.14 with exposure of 0.5 μmol $g^{-1}$ dry wt. in sediment and 0.486 μmol $L^{-1}$ as the PCBZ challenge.

The second area of work was to develop the time dependent response of *H. azteca* to DDE so that DDE could be used as a challenge chemical in place of PCBZ. The water-only toxicity of *H. azteca* to DDE was similar to the toxicity to PCBZ on a body residue basis. In fact, the two time-dependent curves are not different from each other. However, they are very different from the reported time dependence of polycyclic aromatic hydrocarbons. When placed on similar scales, the toxicity of DDE after about 48 h shows little time dependence while that for the PAH show

significant time dependence, and the body residues to produce a toxic response are much larger for PAH.

The third area of effort was a joint experiment with fluoranthene and DDE run at Vicksberg with *Leptocherius plumulosus* exposed to sediment sorbed compounds in a factorial designed experiment. The experiment was only partly successful in that the mortality was not at the expected level in all doses. However, the DDE $LR_{50}$ could be calculated at 0.130 (0.142-0.122) μmol $g^{-1}$(fw) with only DDE and 0.118 (0.129 – 0.111) μmol $g^{-1}$(fw) in the presence of 0.01 ± 0.002 μmol $g^{-1}$(fw) of PAH.

## Results

*Pyrene and Pentachlorobenzene Exposures*. *Hyalella azteca* had previously been exposed to mixtures of pyrene and PCBZ in aqueous exposures and the result was evidence that additivity could be demonstrated on a toxic unit basis. Thus, to continue the work for evaluating benthic organisms exposed to sediments and subsequently challenged with PCBZ, *H. azteca* were exposed to sediments containing pyrene and challenged with PCBZ in overlying water. The light regime was varied. In the dark and under yellow light there was little evidence that the method would work because the response was not different from exposures containing only PCBZ as the concentration for 50 percent mortality required 0.8 ± 0.4 toxic units (TU). This was the result of *H. azteca* failing to accumulate the pyrene. Two likely causes were investigated. The first was that the sediment bioavailability was too limited. The first sediment (approximately one percent organic carbon) was replaced with a low organic carbon sediment (0.4 percent OC), but the result was the same with very low pyrene in the organisms. The bioavailability was examined with exposure of *Lumbriculus variegatus* to the same sediment and the use of Tenax® resin extraction. Both measures exhibited good evidence of bioavailability. Thus, the problem was thought to be the light regime under which the tests were performed. It appeared that the *H. azteca* were only exposed to the overlying water particularly in the presence of PCBZ. Since *H. azteca* are negatively phototrophic, white light should encourage the organisms to stay in the sediment.

While the initial thought was to avoid white light which will force the *H. azteca* into the sediment due to the potential for photoinduced toxicity, previous studies with fluoranthene and various light regimes suggests that the toxicity of the PAH is not enhanced because the organisms stay buried in the sediment when the light is on. Thus, an experiment with two concentrations of pyrene using three concentrations of PCBZ was employed to study the challenge problem. In this case, pyrene was accumulated by the amphipods but the extent of toxicity was much greater than anticipated. Even in the absence of PCBZ there was substantial mortality. In fact, the extent of mortality was greater in these studies than previously observed in water only exposures at the same body residue levels. Water only exposures under yellow light yielded 2 d $LR_{50}$ estimates of 4.14 μmol $g^{-1}$. In this study, the estimate in the absence of PCBZ was 56.6 μmol $g^{-1}$ and between the response of *H. azteca* under fluorescent and UV enhanced light observed at 10 d exposure. This suggests that the *H. azteca* were likely experiencing photoinduced toxicity or there is some additional toxicant in the system that is not evident based on the control mortality which was greater than five percent. The estimate for the

$LR_{50}$ is not very strong because the data were either zero and near 100 percent mortality. There was no statistical difference between the estimated body residue required to produce mortality in the presence of PCBZ dosed at 250 μg $L^{-1}$ which is likely the result of having the very high mortality. At least by using white light, *H. azteca* did accumulate pyrene and it was toxic. This experiment will need to be repeated with lower pyrene concentrations to determine whether the overall approach will work. So far we have found both ends of the spectrum. In the case of no accumulation of pyrene, the toxicity was only due to PCBZ; and in the case of high toxicity by pyrene, the amount of PCBZ required for toxicity was minimal (approximately 0.2 TU of PCBZ).

*Time Dependent DDE Toxicity in H. azteca. Hyalella azteca* were exposed to DDE solutions with 24 h renewal of the water concentration. As with the PCBZ, the water concentration declined during the 24 h exposure by approximately 50 percent. However, as with PCBZ, the elimination is slow 0.009 ± 0.006 $h^{-1}$ (mean ± SD, n = 14) measured across all concentrations and all experimental time frames. This elimination rate is somewhat slower that that found for PCBZ (0.014 $h^{-1}$) but not statistically different. Unlike PCBZ, the uptake rate for DDE is much faster (347 ± 88 mL $g^{-1}$ $h^{-1}$) leading to much higher bioaccumulation factors 44,962 ± 23,523 where the PCBZ BCF was about 500 – 2200. There was also no apparent impact of increasing concentration on the bioaccumulation factor for DDE. The exposure range for the DDE was much lower, ranging from 0.40 to 14.1 μg $L^{-1}$ while that for PCBZ ranged from 66.5 μg $L^{-1}$ to 1 mg $L^{-1}$ which reflects the relative solubility limits for the two compounds.

The body residues required for 50 percent mortality were, however, very similar for the two compounds. For DDE, as with PCBZ, the method for determining the body residue did not affect the time dependence. The temporal change in the concentration required to produce toxicity shows a steep time response. This was essentially the same temporal response found for PCBZ. Thus, both compounds are equipotent on a molar basis suggesting that they have the same mechanism of toxicity in *Hyalella azteca*. When the data is fit to the damage assessment model, it is possible to obtain an estimate for the rate of damage repair ($k_r$), which was found to be 0.038 $h^{-1}$. This rate is essentially the same as that for PCBZ. With the above data it is possible to obtain interpretation of the toxicity of DDE with any duration of exposure for *Hyalella azteca*. These data expand our ability to interpret body residue data and to better understand the impact of multiple pulsed exposures as might occur in the field.

The toxicity of DDE to *Hyalella azteca* was substantially different from previously reported temporal toxic responses to PAH congeners. The temporal response of DDE was minimal relative to that for pyrene and at long exposures the body residue values required to produce a toxic response tend to converge. Thus, if one is going to assess the toxicity of a mixture of PAH with DDE as a challenge compound in *Hyalella azteca*, then the evaluation cannot be done strictly on an additive molar basis but must be done on a toxic unit basis. If the exposures for the challenge experiment are performed within the range of 4 to 28 d exposure, then essentially DDE will exhibit a constant value for the $LR_{50}$ against which to compare the response in the mixture.

*10 d DDE and PAH Exposures in Leptocherius plumulosus*. *Leptocherius plumulosus* were exposed to DDE and mixture of PAH in sediment exposures for 10 d. The experimental design was set to establish both the toxic response for DDE only and DDE in the presence of differing concentrations of PAH mixture. The $LR_{50}$ based on measured DDE concentrations was 0.13 (0.142-0.122) μmol $g^{-1}$ DDE. In the presence of the lowest concentration of PAH, the $LR_{50}$ was estimated to be 0.118 (0.129 – 0.111) μmol $g^{-1}$(fw) DDE suggesting that the DDE contributed approximately 0.90 TU to the mixture and not significantly different than DDE only exposures.

The measured concentration of PAH in the organisms was 0.01 ± 0.002 μmol $g^{-1}$ measured as the sum of PAH. Assuming that all the PAH were as sensitive as fluoranthene, the number of TU represented by the PAH would be 0.04. Thus, the toxicity was largely contributed by the DDE. Therefore, it is clear that PAH accumulation was limited and did not contribute significantly to the toxic response.

## Publications

Landrum, P.F., J.A. Steevens, D.C. Gossiaux, M. McElroy, S. Robinson, L. Begnoche, S. Chernyak and J. Hickey. 2004. Time-dependent lethal body residues for the toxicity of pentachlorobenzene to *Hyalella azteca*. *Environ. Toxicol. Chem.* 23(5):1335-1343..

Yoo, L.J., J.A. Steevens and P.F. Landrum. 2003. Development of a new bioaccumulation testing approach: the use of DDE as a challenge chemical to predict contaminant bioaccumulation. ERDC/TN EEDP-01-50, U.S. Army Corp of Engineers, Vicksberg, Mississippi. http://libweb.wes.army.mil/uhtbin/hyperion/EEDP-01-50.pdf.

Steevens, J.A. and P.F. Landrum. 2002. Development of a biological-effects-based approach to assess the significance of contaminant bioaccumulation. EEDP Technical Notes Collection (ERDC/TN EEDP-01-48), US Army Engineer Research and Development Center, Vicksburg, Mississippi.

## Presentations

Yoo, J.L.J., J.S. Steevens and P.F. Landrum. 2003. Using DDE as a challenge chemical to predict effects of contaminant bioaccumulation. 24th Annual Meeting of the Society of Environmental Toxicology and Chemistry. November 8-13. Austin, Texas.

Gossiaux, D.C., P.F. Landrum, M.J. McElroy, S.D. Robinson and J.A. Steevens. 2003. Sediment exposures to *Hyalella azteca* using a challenge exposure approach in varying light regimes. 24th Annual Meeting of the Society of Environmental Toxicology and Chemistry. November 8-13. Austin, Texas.

Yoo, J.L.J., J.A. Steevens and P.F. Landrum. 2003. Using DDE as a challenge chemical to predict effects of contaminant bioaccumulation. Mid-South Regional Meeting SETAC. July 10-11. Nashville, Tennessee.

Gossiaux, D.C., P.F. Landrum, J.A. Steevens, M.J. McElroy, S.D. Robinson, L. Begnoche, S. Chernyak and J. Hickey. 2002. Comparison of the time-dependent toxicity of DDE and pentachlorobenzene in the amphipod *Hyalella*

*azteca*. The 23rd Annual Meeting of the Society of Environmental Toxicology and Chemistry, North America. November 16-20. Salt Lake City, Utah.

Landrum, P.F., J.A. Steevens, D.C. Gossiaux, M. McElroy, S. Robinson, L. Begnoche, S. Chernyak and J. Hickey. 2002. A challenge approach to assess bioaccumulated residue. The 23rd Annual Meeting of the Society of Environmental Toxicology and Chemistry, North America. November 16-20. Salt Lake City, Utah.

Landrum, P.F., J.A. Steevens, D.C. Gossiaux, M. McElroy, S. Robinson, S. Chernyak, L. Begnoche, and J. Hickey. 2002. Developing a bioassay approach for assessing the hazard of bioaccumulated residues for benthic organisms using pentachlorobenzene as a challenge compound. The 12th Annual Meeting of the Society of Environmental Toxicology and Chemistry, Europe. May 12-16. Vienna, Austria.

## Additional Funding

This work was funded in part by the U.S. Army Corps of Engineers.

## CA4/IV-05: Implications of Cercopagis and Bythotrephes to Alewife Recruitment and Stability of the Lake Michigan Pelagic Food Web

*Principal Investigator: Henry Vanderploeg, Great Lakes Environmental Research Laboratory; Doran Mason, Great Lakes Environmental Research Laboratory and Thomas H. Johengen, University of Michigan*

NOAA Strategic Goal 1

## Summary

We propose to develop a general model from experimental observations of prey selection and feeding for the invading predatory cercopagid cladocerans *Cercopagis pengoi* and *Bythotrephes longimanus* (Figure 1) that will be useful for predicting predatory impact of these cercopagids. We will combine this information along with field observations of population dynamics, production and spatial distribution of zooplankton and fishes collected in this and related projects to describe and understand invasion dynamics of *Cercopagis* and determine if these cercopagids have disrupted the Lake Michigan food web. We hypothesize that alewife predation on *Bythotrephes*, a competitor and predator of *Cercopagis* (this study), has allowed *Cercopagis* to invade nearshore waters of the spatially complex Lake Michigan. We are also examining whether both these cercopagids have created a bottleneck for recruitment of young of year alewife and other fishes. In a new approach, we are exploring the use of sequential sediment traps to define population dynamics of cercopagids, including proportion killed by fish predation. Work in CY 2004 will focus on spatial distribution and predatory interactions among zooplankton, *Bythotrephes*, *Cercopagis*, *Mysis*, and Y0Y and adult alewives.

## Scientific Rationale

Radka Pichlová (supported on a related project sponsored by the Great Lakes Fishery Commission) and Henry Vanderploeg have been doing experimental work on food web interactions of the Ponto-Caspian predatory cladoceran *Cercopagis*, which invaded Lake Michigan in 1999, and competition and predatory interactions with *Bythotrephes*, a larger predatory cercopagid of Palaearctic origin that invaded Lake Michigan in 1985 (Figure 1). It is of great importance to invasion theory how *Cercopagis*, so very similar to the already established *Bythotrephes*, found a "niche" in Lake Michigan. The major concern about both species of cercopagids is that they may compete with small fishes such as larval and young of year (YOY) alewife and perch for zooplankton (Figure 2) (Francis et al, 1996; Vanderploeg et al, 2002). The tail spine of both cercopagids (Figure 1) foils predation by small fishes; however, cercopagids may be preferred prey of large fishes (Figure 2) (Vanderploeg et al, 2002). Because cercopagids have high reproductive output, high feeding rates and can prey on cladocerans large relative to their body size, they could be serious competitors with larval and small fishes (Figure 2).

## Progress

We carried out an ambitious field monitoring and experimental program to examine population dynamics of the newly invading *Cercopagis* on alewife recruitment and the pelagic food web of Lake Michigan. The project extended our field monitoring activities started in EEGLE and a study of alewife recruitment carried out by Doran Mason (Great Lakes Environmental Research Laboratory) and Ed Rutherford (University of Michigan). Field sampling at M110, M45, M15, and C (Muskegon Lake) for nutrients, chlorophyll and zooplankton was completed in March through December in 2002 and 2003, with monthly collections during spring and fall and biweekly during the summer. These collections supported our long-term time series to examine post-invasion population dynamics of the two cercopagids. We will explore use of the egg ratio to examine birth rates of the prey of the cercopagids. Usefulness of this approach depends on how well the preserved zooplankton retained their eggs. This analysis will be done at the time we measure zooplankton lengths for biomass determinations. Many of the zooplankton collections have been counted but few have been sized. Egg ratios, spine lengths, and biomass of the cercopagids have been determined for 2000-2002; therefore, these measurements need to be done for 2003 and 2004.

We made good progress in both experimental (see presentation titles by Vanderploeg et al, Pichlová et al, Cavaletto et al, and Carter et al for ASLO and IAGLR) and fieldwork, including carrying out the fieldwork necessary for a study of spatial distribution of zooplankton and alewives and feeding preferences of alewives as they relate to *Cercopagis* and *Bythotrephes* abundance. The spatial and field study will be very important for understanding how *Cercopagis* found a niche in Lake Michigan and the role of alewives in creating this niche.

To examine potential food-web impacts and interactions, Radka Pichlová has been doing experiments in large bottles and small enclosures to determine prey selection and feeding rates of *Cercopagis* and *Bythotrephes* on different Great Lakes zooplankton, predatory interactions among *Bythotrephes*, *Cercopagis*, and *Leptodora* (a

native predatory cladoceran). Preliminary results show that *Cercopagis* prefers smaller prey than *Bythotrephes*. For example, she showed *Cercopagis* would eat small zooplankton such as copepod nauplii, *Bosmina*, and zebra mussel larvae. Although much has been done, much more work on prey selectivity and functional response to prey concentration remains for both species. Preliminary insights into feeding mechanisms were obtained by direct observation with video: *Cercopagis* are slower than *Bythotrephes* and thus may be less adept at capturing quick, agile prey like copepods.

In 2001 and 2002 Doran Mason and colleagues (the larval fish team) carried out a field project of extensive sampling of zooplankton and larval fishes, May through October, in Muskegon Lake and in nearshore and offshore regions of Lake Michigan in support of the research grant "Dynamics of Alewife Recruitment Variability in Lake Michigan" (PI's: Edward Rutherford, University of Michigan; Doran Mason, Great Lakes Environmental Research Laboratory; Charles Madenjian, USGS Great Lakes Science Center; and William Patterson, Syracuse University). The larval fish team is examining the role of drowned river mouths such as Muskegon Lake in comparison with nearshore and offshore Lake Michigan for supporting alewife recruitment. In theory, the warm, nutrient- and zooplankton-rich drowned river mouths should support enhanced growth and survival of larval and YOY alewives relative to Lake Michigan proper.

To understand invasion dynamics and document impacts of *Cercopagis* on alewife recruitment, the zooplankton team (Vanderploeg, Cavaletto, Pichlova, and a summer fellow) examined zooplankton samples collected summer and fall of 2001 and March through December in both 2002 and 2003 (biweekly during summer, monthly at other times) from station C, the deepest site in Muskegon Lake, along with samples from M110, M45, M15, the stations on 110-m, 45-m, and 15-m contours of the onshore offshore transect in Lake Michigan at Muskegon, where we have records from a previously funded CILER project, "Changes in the Pelagic Food Web of Southern Lake Michigan (CPFWSLM)," EEGLE and the GLERL monitoring projects.

Although much more work needs to be done on spatial and temporal distribution of zooplankton and feeding interactions of *Cercopagis* and *Bythotrephes*, examination of these preliminary data suggest that *Cercopagis* and *Bythotrephes* are competitors and that *Bythotrephes* preys on *Cercopagis*. We hypothesized that *Cercopagis* distribution and impacts are restricted to the drowned river mouth and nearshore region because of predation from *Bythotrephes*, which in turn may be controlled by adult alewives, since *Bythotrephes* are favored prey of alewives. Alewives and *Bythotrephes* probably structure the plankton at middle depths and offshore waters, respectively. Another factor we are beginning to consider is the role of *Mysis* in altering alewife and cercopagid interactions. Preliminary diet analysis of daytime samples suggests that *Mysis* and *Bythotrephes* are the preferred prey of alewives and that *Cercopagis* is rarely eaten. In deep waters where *Mysis* is abundant, predation pressure may be released on *Bythotrephes*. We are now examining the diet and prey selection of adult and YOY alewives for *Cercopagis*, *Bythotrephes*, *Mysis* and other zooplankton using fish collected in early September 2003 in midwater trawls at night and bottom trawls during day. We are very happy to have collected fish in the midwater trawl, as this can be a difficult feat. These collections of fish were

matched with acoustics for their spatial distribution and with zooplankton net tows collected in three depth ranges: epilimnion, metalimnion, hypolimnion.

Whether *Cercopagis*, *Bythotrephes*, or their prey is seriously depleted by predation depends on predation rate relative to birth rate. Birth rate is affected by food quantity and quality (bottom up effects). We can use the egg-ratio method to estimate population growth rates and to identify areas of high population growth (Muskegon Lake vs. Lake Michigan) for *Cercopagis*, *Bythotrephes*, and other cladocerans (the prey). These estimates of population growth can be compared to estimates of mortality imposed by *Cercopagis*, *Bythotrephes*, and alewives to determine significance of the mortality imposed by predation.

To understand the significance of bottom-up effects of P limitation on planktonic biomass and quality of seston as food for herbivorous zooplankton population growth (reflected in their egg ratios) in these different regions, we measured size-fractioned chlorophyll, total P and seston C:N:P ratios (an indicator of nutritional deficiency of P).

In 2002, the larval fish team finished zooplankton and larval fish sampling in Muskegon Lake and in Lake Michigan to determine the spatial distribution, abundance and diet of first year alewife. The two teams in 2002 and 2003 collaborated to explore simultaneous towing the plankton survey system and 120 KHz split beam acoustic fish to determine vertical distributions of physical variables, chlorophyll fluorescence, zooplankton and larval, juvenile, and adult alewives along a transect through Muskegon Lake to offshore Lake Michigan. All sensors were calibrated with appropriate collections of chlorophyll, zooplankton, and fishes. Vertical profiles of chlorophyll and nutrients were determined at all master stations, and vertical profiles of zooplankton determined by opening closing nets occasionally were determined. The standard limnological variables were successfully collected; however, there were problems in use of the acoustics equipment in both 2002 and 2003 because of faulty equipment and inexperienced operators.

In 2004 we completed another major season monitoring plankton (and nutrient) dynamics, including cercopagids. Also, we examined vertical structure of alewives and zooplankton and collected alewives for diet and selectivity for different zooplankton in the transition zone (45-55 m depth contours), where both *Cercopagis* and *Bythotrephes* coexist. We collected fish by means of bottom and midwater trawling, and stomach contents of the fish will be analyzed later. On the basis of vertical temperature profile measurement (CTD) we sampled zooplankton in the epilimnion, metalimnion and hypolimnion using a choke-off plankton net. We observed vertical migration undergoing in *Daphnia*, *Bosmina*, *Leptodiaptomus*, and *Diacyclops* (major zooplankton species). They all tended to be more abundant in the metalimnion during the day, and more abundant in the epilimnion at night. Thus all migrate with their potential invertebrate predators, *Bythotrephes*, *Cercopagis*, and *Leptodora*. All may be trying to avoid becoming victims of fish predation. Analysis of alewife prey selection from analysis stomach contents and prey abundance in the water column collected earlier suggest that alewives strongly select for *Bythotrephes* over *Cercopagis*, and that *Cercopagis* finds a spatial refuge in nearshore waters, where fishes prey on *Bythotrephes*.

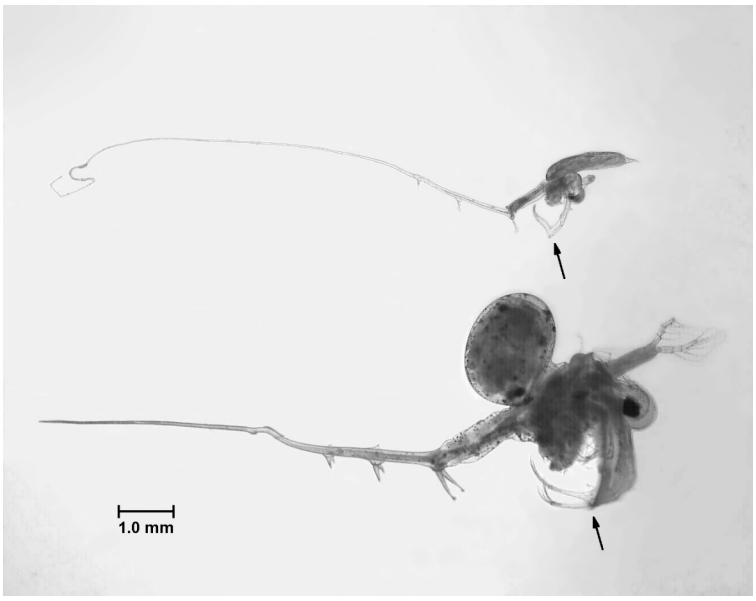


Figure 1. Contrast between morphology and size of *Cercopagis pengoi* (upper) and *Bythotrephes cederstroemi* (lower) collected in Lake Michigan July-August, 2000, in waters of 45-m depth off Muskegon, Michigan. Arrows point to the first thoracopods, which putatively would be important for grasping and holding large prey.

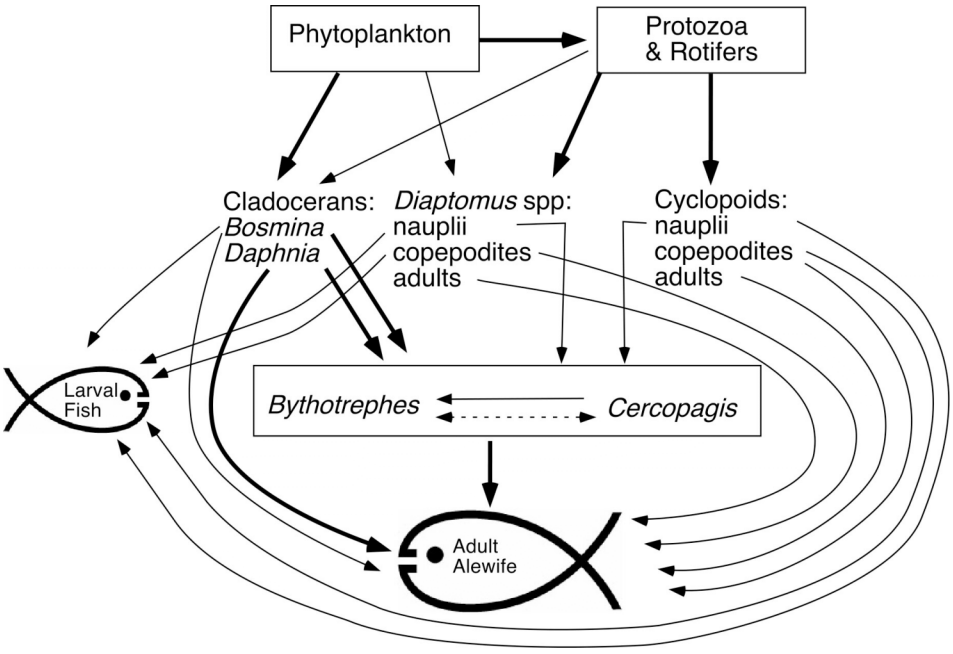


Figure 2. *Bythotrephes cederstroemi* and *Cercopagis pengoi* in the epilimnetic food webs of Great Lakes and their connection to important epilimnetic forage fishes, which would be alewives in Lake Michigan. Thick arrows indicate high selectivities of the consumer and thin arrows indicate low selectivities. We anticipate that *Cercopagis* would prefer smaller cladocerans (*Bosmina*) than would *Bythotrephes*, and that *Cercopagis* could be prey of *Bythotrephes*. The dotted line with two arrowheads on it implies potential competitive interactions because of similar diet preferences.

## Publications

Pothoven, S.A. and H.A. Vanderploeg. 2004. Prey selection and diet of alewife in Lake Michigan: seasonal, spatial, and interannual patterns. *Trans. Amer. Fish. Soc.* (in press).

Vanderploeg, H.A. 2003. Ecological forecasting of impacts of ponto-caspian species in the Great Lakes: describing, understanding, and predicting a system in transition. In Ecological Forecasting: New Tools for Coastal and Marine Ecosystem Management. N. Valette-Silver and D. Scavia (eds.). NOAA Technical Memorandum NOS NCCOS 1, Silver Spring, Maryland, 81-84. http://www.glerl.noaa.gov/pubs/fulltext/2003/20030015.pdf.

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Cavaletto, J.F., H.A. Vanderploeg, M.A. Agy, P.J. Lavrentyev, J.R. Liebig, G.A. Lang and M.H. Bundy. 2003. Inshore or offshore: where are the copepods during winter and early spring in southern Lake Michigan? ASLO Aquatic Sciences Meeting, February 8-14. Salt Lake City, Utah.

Pichlova, R., H.A. Vanderploeg, J.F. Cavaletto, and L. Stara. 2003. *Cercopagis pengoi* after three years since invasion to Lake Michigan: changes of population and impact on the food web. ASLO Aquatic Sciences Meeting. February 8-14. Salt Lake City, Utah.

Vanderploeg, H.A., T.H. Johengen, P.J. Lavrentyev, G.A. Lang, J.R. Liebig, C. Chen, M.H. Bundy, J.F. Cavaletto and B.J. Eadie. 2003. Fronts and plumes as organizers of spatial distribution of nutrients and plankton on Lake Michigan: consequences to the food web. ASLO Aquatic Sciences Meeting. February 8-14. Salt Lake City, Utah.

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Vanderploeg, H.A., R. Pichlova, S.A. Pothoven, J.F. Cavaletto, G.S. Carter, D.M. Mason, T.O. Hook and E.S. Rutherford. 2003. Finding a niche in the Great Lakes: the emerging *Cercopagis* story. The 46th Conference on Great Lakes Research, International Association for Great Lakes Research and International Lake Environment Committee. June 22-26. Chicago, Illinois.

Carter, G.S., D.M. Mason, E.S. Rutherford, T.O. Hook, J.F. Cavaletto, R. Pichlová and H.A. Vanderploeg. 2003. Competitive interactions between larval alewife (*Alosa pseudoharengus*), *Bythotrephes cederstroemi* and *Cercopagis pengoi* in Lake Michigan: implications for alewife growth and alteration of nearshore zooplankton assemblages. The 46th Conference on Great Lakes Research, International Association for Great Lakes Research and International Lake Environment Committee. June 22-26. Chicago, Illinois.

## CA4/IV-07: Protocol Development for Monitoring Great Lakes Wetlands

*Principal Investigator: Stephen Lozano, Great Lakes Environmental Research Laboratory*

NOAA Strategic Goal 1

### Project Rationale

Great Lakes wetlands perform many important functions in the aquatic habitat. They are complex ecosystems that support high biological productivity, dynamic exchanges of nutrients between land and water, and play crucial roles in shoreline stabilization and protection. Urban development has resulted in the degradation of many of our wetlands and near coastal waters and loss of critical ecosystem and economic functions. Under the Coastal Zone Management Act of 1972, a program was established for the restoration of coastal habitats across the United States and its territories, stressing a comprehensive approach to maximizing benefits derived from projects. Under the Estuarine Restoration Act, an estuary is defined as the part of a river or stream or other body of water that has an unimpaired connection with the open sea and where the seawater is measurably diluted with fresh water derived from land drainage. The term was broadened, however, to include near coastal waters and wetlands of the Great Lakes that are similar in form and function to estuaries, including the area located in the Great Lakes biogeographic region and designated as a National Estuarine Research Reserve under the Coastal Zone Management Act of 1972 (this is Old Woman Creek Reserve).

Estuary habitats include the physical, biological, and chemical elements associated with an estuary, including the complex of physical and hydrologic features and living organisms within the estuary and associated ecosystems. Restoration of estuary habitat includes those activities that result in improving degraded estuaries or estuary habitat or creating new estuary habitat (including both physical and functional restoration), with the goal of attaining a self-sustaining system integrated into the surrounding landscape.

This research project is designed to determine the important ecosystem structures and functions of Great Lakes wetlands that must be protected when developing the monitoring protocols and standards for all future research projects that fall under the Estuary Restoration Act. It is anticipated that even given the diversity of habitats to potentially be restored and the extreme latitudinal range across which these habitats occur, there are consistent principles and approaches that form a common basis for effective monitoring, regardless of the habitat considered. This research will provide a quantitative basis for assessing the impact of a restoration project and will assist in the development and implementation of monitoring plans for projects potentially occurring in any or all of these habitats.

Based on the research conducted within this project, the impact of a restoration initiative, both positive and potentially negative, may be quantified.

## Background

An estuary is a semi-enclosed body of water in which there is a measurable mixing of salt and fresh water. The mixing of fresh and salt water that unites these geographic features is a result of the estuary's interconnection with adjacent ecosystems and creates an environment highly variable in terms of salinity, nutrients, water levels, and temperature. Numerous species of plants and animals that can tolerate the range of physical and chemical characteristics thrive in these habitats. Estuaries as a whole are highly dependent on inputs, including surface and subsurface freshwater, atmospheric exchange and deposition, and movements of salt water and organisms from adjacent ocean waters. Estuaries also export significant amounts of material, contributing low salinity water, organic material, organisms, and nutrients to nearshore waters. Estuaries are among the most productive ecosystems on earth. Bay and estuarine systems directly or indirectly support some of the most profitable fisheries, as well as provide habitat, food, and resting places for numerous endangered and recreationally important species. In fact, in some coastal areas, estuarine-dependent species comprise 70 to 90 percent of the fish and shellfish commercial landings.

Despite the importance of estuaries for their support of healthy natural ecosystems and regional economies, estuaries throughout the U.S. are in a state of decline. While the reasons for decline are as varied as the systems themselves, human impacts are consistently a primary or contributing factor. Physical and hydrologic modification of coastal areas for development, agriculture, and industry have directly removed productive habitat and shoreline buffer areas that are essential to protecting estuaries from upland runoff and other associated activities. Runoff and point sources have contaminated sediment and organisms, as well as resulting in an over enrichment and eutrophication of coastal waters. Critical function within these productive estuarine habitats has been impaired or lost entirely. This impairment has resulted in reduced value to the user communities in areas surrounding the estuary. Fortunately, what has been lost or impaired can, in many cases, be restored.

Coastal restoration is the process of reestablishing a self-sustaining habitat that, in time, can come to resemble a natural condition in terms of structure and function. Fully functioning restored systems are resilient, self-sustainable, and produce a quantity and diversity of organisms of similar composition to natural or reference systems. Part of this full functionality includes structural components such as a certain minimum level of water quality; sediment that is not contaminated, appropriate grain sizes; hydrodynamics that allow for removal or dilution of wastes/pollutants and colonization or dispersal of new recruits; and an abundance and diversity of flora and fauna similar to natural systems. Because of the recognized need for coastal restoration, programs have been established across the country to conduct restoration planning and design and build projects in specific bay systems. Nation-wide programs are much less common.

## Work Plan

This research was intended to document the links between nearshore and coastal zones and Great Lakes wetlands and provide new insights into the importance that wetlands play in preserving the ecosystem integrity of coastal and nearshore waters of the Great Lakes. Project results will be useful for developing plans for conserving and restoring coastal estuaries and its critical habitats. Furthermore, it will provide a foundation for future wetland studies that will directly address land-water nutrient exchange, cycling of contaminants and nutrients, and the exchange of biota between the nearshore zone and open lake. We conducted the following activities to advance our objectives.

- Review of literature and interview scientists for understanding the role of different coastal habitats in preserving the integrity of Great Lakes water quality.
- Review literature and develop lists of structural and functional characteristics of identified Great Lakes coastal habitats that should be evaluated in any restoration plan, denoting those that are critical as restoration success metrics.
- Review literature and document the role of sediment characteristics including level of contamination, grain sizes and total organic carbon in preserving the integrity of Great Lakes water quality.
- Review literature and document the role that the hydrodynamic conditions allow for removal or dilution of wastes/pollutants and colonization or dispersal of new non-indigenous recruits to Great Lakes wetlands.

## Overview of Research Findings

The objective of the documents developed as part of this project is to provide technical assistance in the development and implementation of sound scientific monitoring of coastal restoration efforts. Volume One (hard copies available) outlines the steps necessary in the development of a scientifically sound and fiscally responsible monitoring plan and provides tools to assist in monitoring plan development and guide decision making. The following coastal habitat types are addressed: water column, oyster reef, coral reef, soft bottom, hard shoreline, soft shoreline, submerged aquatic vegetation, emergent march, mangroves, deepwater swamps, bottomlands, and kelp and other macroalgae. Specific structural and functional characteristics for each habitat type are listed and prioritized to provide guidance in selecting characteristics to be monitored. Volume Two (to be released Fall 2004) contains more detailed explanations of these structural and functional characteristics, a review of literature on monitoring and sampling methods and restoration case studies, and a list of experts who have agreed to make themselves available for more detailed guidance. Other tools provided in volume Two include: an annotated bibliography of sampling techniques manuals (including AQ/QC documents) for each habitat type, a review of regional monitoring programs across the United States, a review of relevant Federal Acts, a sample list of costs involved in the monitoring implementation, and a review of the socio-economic issues associated with restoration monitoring. In developing this guidance, it has been recognized that individual restoration and monitoring projects must be judged in the context of their spatial and temporal environments as well as their relationship

to other regions and habitats within the watershed. Well-planned restoration projects and planning efforts are guided not only by sound science but also socio-economic goals for the particular estuarine ecosystem, reflecting community uses and values.

## Publications

Thayer, G.W., T.A. McTigue, R.J. Bellmer, F.M. Burrows., D.H. Merkey, A.D. Nickens, S.J. Lozano, P.F. Gayaldo, P.J. Polmateer, and P.T. Pinit. 2003. Science-based restoration monitoring of coastal habitats. Volume One: A Framework for Monitoring Plans Under the Estuaries and Clean Waters Act of 2000 (PL 160-457). NOAA Coastal Ocean Program Decision Analysis Series No. 23. Volume 1. NOAA National Centers for Coastal Ocean Science, Silver Spring, Maryland. 35 pp. plus appendices.

Merkey, D.H. 2003. Restoration monitoring of freshwater coastal habitats. In US NOAA Coastal Services Center. Coastal Zone 03. Proceedings of the 13th Biennial Coastal Zone Conference. Baltimore, Maryland. July 13-17. NOAA/CSC/20322-CD. CD-ROM. Charleston, South Carolina: NOAA Coastal Services Center.

## Presentations

Merkey, D.H. 2003. Science-based restoration monitoring of coastal habitats Volume Two: Tools for Monitoring Coastal Habitats. Restoration Monitoring of Freshwater Coastal Habitats. Coastal Zone Conference. Baltimore, Maryland.

Thayer, G.W., R.J. Bellmer, T.A. McTigue, F.M. Burrows, D.H. Merkey, A.D. Nickens, S.J. Lozano and P.T. Pinit. 2003. Science-based restoration monitoring of coastal habitats, Volume 1: A Framework for Monitoring Plans under the Estuaries and Clean Water Act of 2000 (PL 160-457). Restore America's Estuaries Inaugural Conference, Baltimore, Maryland.

## Significant Interactions

Significant interactions with a variety of universities, businesses, NGOs, and federal agencies have been made while working on this project. Experts in the field of freshwater habitat restoration and monitoring were contacted for input into the documents produced and several reviewed various chapters for publication. A partial list of organizations contacted during this project includes (in no particular order): NOAA/Great Lakes Environmental Research Laboratory, NOAA, National Centers for Coastal Ocean Science, NOAA/Coastal Services Center, NOAA/National Marine Fisheries Service, the New Jersey Marine Sciences Consortium, Barry A. Vittor & Associates, Inc., McMaster University, Pennsylvania State University, University of Wisconsin, US Geological Survey, Clemson University, East Carolina University, Tennessee Tech University, Louisiana State University, University of Washington, California State University, US Environmental Protection Agency, and Coastal Caroline University

## CA4/IV-08: Assessment of in situ Early Diagenesis of Organic Geochemical Proxies Employed in the Great Lakes Paleoenvironmental Reconstructions

*Principal Investigators: Philip Meyer, University of Michigan and Brian J. Eadie, Great Lakes Environmental Research Laboratory*

NOAA Strategic Goal 1

### Background

Organic matter components of sediments constitute an important part of the fossil record used to reconstruct environments of the past. Sedimentary organic matter provides evidence of past biota and former environmental conditions in its molecular, isotopic, and elemental composition (e.g., Meyers, 1997). The amounts and types of organic matter in sediments thereby contribute in significant ways to paleoenvironmental and paleoclimatological records and reconstructions. Biomarker molecules, in particular, are especially informative as "geochemical fossils".

However, only a small fraction of the original amount of biosynthesized organic matter survives to become part of the sedimentary record of past environments (e.g., Eadie et al, 1984). Alteration and destruction of organic matter occurs during sinking and is particularly severe in the upper few centimeters of sediments (e.g., Hodell and Schelske, 1998). Degradation rates of the various components of organic matter differ among the range of molecular types that comprise this material and lead to selective diagenetic losses (e.g., Goossens et al, 1989; Meyers and Eadie, 1994). In addition, sediment microbes synthesize new components that partially replaces the organic matter that is initially deposited.

A critical question in view of the known changes that occur to the amount and character of sedimenting organic matter is "How accurately does the organic matter in sediments reflect the original sources and environmental conditions?". In order to reconstruct paleoenvironments more accurately, assessment of the amount of early diagenetic alteration of the isotopic and biomarker compositions of sediment organic matter is needed. Such knowledge will enable interpretive corrections for the probable modifications of the organic geochemical paleo-environmental information available in sediments.

### Rationale

This project builds upon activities and collaborations established under a CILER Science Enhancement project (CA4/I-07SE: Molecular and Isotopic Paleo-temperature Proxies in the Great Lakes Sediments: Keys to Climate Projection? - see pp. 9-11 of this report). For this extended project, we will attempt to quantify the extent of early diagenetic alterations to sedimentary isotopic and molecular records so that organic geochemical paleoenvironmental reconstructions can be created with minimal diagenetic skewing. It will compare molecular distributions of biomarker-type compounds in sediment samples from the same age horizons collected 21 years apart from the same location. This is a novel and unprecedented opportunity to assess *in situ* diagenesis by analyzing the same sediment horizon under natural burial conditions. The study will be sited in Lake Erie, where elevated sedimentation rates provide the highest resolution in the Great Lakes (approximately two years). Sediments ranging in age from modern to about 100 years old will be studied to assess possible continuing impacts of longer term diagenesis. Compounds that will

be studied are straight- and branched-chain alkanes, which will be used as representatives of biomarkers having low susceptibility to alteration; straight-chain alkanols, which are representatives of moderately reactive molecules; and carboxylic acids, which represent relatively reactive and thus more readily altered biomarker molecules. These analyses will be done against a backdrop of the well-documented changes in algal productivity and organic matter delivery that will provide a rigorous evaluation of the robustness of the Lake Erie biomarker proxy record.

## Samples and Procedures

The Lake Erie Eastern Basin Reference Site will provide the high-resolution sediment cores that constitute the most critical element needed for the success of our project. A core obtained at this location in 1981 has been dated by $^{210}Pb$ analysis. The 1.4 m core spans 90 years of sedimentation history, and its sharp $^{137}Cs$ peak shows that mixing has not jeopardized its exceptional time resolution. The core has been divided into 1-cm intervals that approximate sub-annual to annual periods of sediment accumulation. These intervals have been stored frozen since collection to protect their biomarker molecule contents from microbial degradation. We will obtain new cores during September 2002 from the Eastern Basin Reference Site. One core will be dedicated to comparison of the organic matter that has resided in the lake bottom since 1981 with that of the core that has been "frozen in time" to evaluate the effects of *in situ* early diagenesis. Several same-age sediment horizons from multiple new cores will be compared to assess natural variability in organic geochemical compositions so that robust statistical treatment of our analytical results can be done.

$CaCO_3$ contents will be determined by treatment of dried core samples with dilute HCl to release $CO_2$ from carbonate minerals in a carbonate bomb apparatus in the Organic Geochemistry Laboratory at the University of Michigan. The carbonate-free residue remaining after the carbonate bomb determination will be analyzed using a Carlo Erba 1500 CHN analyzer. This procedure yields organic carbon concentrations and organic C/N ratios. Organic matter $^{13}C/^{12}C$ and $^{15}N/^{14}N$ ratios of the carbonate-free samples will be measured at the Great Lakes Environmental Laboratory using a VG PRISM mass spectrometer.

Extraction of biomarker molecules will be done in the Organic Geochemistry Laboratory at the University of Michigan. Biomarkers will be isolated by extraction with double-distilled dichloromethane using sonication. Extracted geolipids will be treated with methanolic-boron-trifluoride to convert fatty acids into their methyl esters prior to separation into subfractions. Extracts will be separated into geolipid subfractions (saturated and monounsaturated hydrocarbons, aromatic and polyunsaturated hydrocarbons, carboxylic acids, alkanols and sterols, long-chain ketones) by silica gel column chromatography. The alkanols will be converted to their trimethylsilyl derivatives with BSTFA prior to gas chromatographic analysis.

The alkane, alkanol, and fatty acid biomarker subfractions will be analyzed by gas chromatography using capillary columns in a Hewlett Packard 5890-II coupled with a Hewlett Packard ChemStation data system and equipped with a FID detector and an on-column injector system. A Hewlett Packard 5890 capillary gas

chromatograph with an MSD detector is also available for use in this project at the Great Lakes Environmental Laboratory.

## Progress

Prior progress for this project is previously described under the Science Enhancement project CA4/I-07SE. For this year, we have compared our earlier measurements of aquatic productivity proxies – inorganic and organic $\delta^{13}C$ values, total $\delta^{15}N$ values, and organic carbon mass accumulation rates at 1 cm intervals in cores of Lake Erie sediment that span the period 1895 to 1991 to new measurements done a core collected in September 2003. Increases in inorganic and organic $\delta^{13}C$ values, $\delta^{15}N$ values, and organic carbon accumulation starting in 1960 reflect the heightened productivity caused by anthropogenic nutrient increase to lake Erie. Decreases in productivity since 1990 illustrate the remedial success of controls on nutrient delivery. Current research activity includes detailed comparisons of elemental and isotopic productivity proxies from same-age sediment horizons in cores frozen since 1983 and 1988 to those in the new 2003 core for evidence of in situ alterations. Near-future activity will include extractions and comparisons of biomarker molecule compositions in the same-age sediment horizons.

## Future Activities

The research we describe in this project is an expression of our continuing interest in understanding how organic matter is produced, delivered, and preserved in the sediments of the Great Lakes. It also forms part of our long-term plans to investigate the history of natural and anthropogenic paleoenvironmental changes in the Great Lakes region. After we have assessed the organic geochemical integrity of paleoenvironmental proxies from our comparison of the century-long Lake Erie cores, we plan to explore longer periods of deposition history and, in particular, transitions into and out of the Little Ice Age over the past millennium. In addition, we wish to test applications of compound-specific isotopic compositions of organic molecules to identify product-precursor relations in paleoenvironmental proxies in Great Lake sedimentary records. These goals will be the basis of future proposals to the NOAA Office of Global Change Program and the NSF Earth System History Program.

## Publications

Knowlton, C.K., P.A. Meyers, B.J. Eadie, J.A. Robbins and M. Lansing. 2004. Impacts of eutrophication on carbon burial in Lake Erie. *Limnology and Oceanography* (in preparation).

## Presentations

Knowlton, C., P.A. Meyers, B.J. Eadie and J.A. Robbins. 2003. Oxygen, carbon, and nitrogen isotopic evidence of environmental changes in eastern Lake Erie over the past century. American Geophysical Union Annual Meeting. San Francisco. Abstract published as *EOS, Transactions American Geophysical Union* 84(46), Fall Meeting Supplement, Abstract B41A-02.

## Significant Interactions

Various elements of the research done during the course of this project have led to fruitful interactions with the lake sediment paleoclimate study directed by Dr. Jane Teranes, Scripps Institution of Oceanography, and the lake sediment paleo-productivity studies directed by Professors Nathaniel Ostrom and Peggy Ostrom, Michigan State University.

## Additional Funding

No additional funding has yet been received. A proposal (Multi-proxy record of millennial and centennial climate changes in sediments of the Great Lakes region) has been submitted to NSF Division of Atmospheric Sciences.

## Student Participation

Christina K. Knowlton, MS in geological sciences, University of Michigan, May 2003. Molecular and isotopic paleoenvironmental proxies in Lake Erie sediments. Christina is currently employed as a hydrologist by the US Geological Survey in Lincoln, Nebraska.

Yuehan Lu, PhD in geological sciences, University of Michigan, expected completion August 2006. Organic geochemical post-glacial paleoclimate reconstruction of the eastern Great Lakes region.

# CA4/IV-09: Ecology of Lake Whitefish Responses to Changes in Benthic Communities in Lake Huron

*Principal Investigator: Thomas Nalepa, Great Lakes Environmental Research Laboratory*

NOAA Strategic Goal 1

## Research Rationale and Plan

The benthic amphipod *Diporeia* is the dominant benthic macroinvertebrate in offshore waters of the Great Lakes (greater than 70 percent of total benthic biomass at depths greater than 30 m) and serves as a major trophic link between pelagic productivity and fish. As a detritivore, this glacial-relict amphipod ingests organic material settled from the water column (mainly diatoms) and, in turn, is fed upon by most species of fish. Because of this ecosystem role, *Diporeia* is considered a keystone organism in the movement of energy between trophic levels in the offshore zone. Recently, densities of *Diporeia* have declined in Lakes Michigan, Erie, and Ontario, and large areas are now completely devoid of this organism (Dermott and Kerec 1997; Nalepa et al, 1998; Lozano et al, 2001). While exact causes of the decline in *Diporeia* are still not clear, in each of the lakes the decline was coincident with the establishment and spread of the zebra mussel, *Dreissena polymorpha.*

Recent studies suggest that the decline in *Diporeia* is leading to decreases in the condition and growth of fish species that heavily depend upon it as a source of food. For instance, in Lake Michigan declines in lake whitefish condition were noted

soon after populations of *Diporeia* decreased (Pothoven et al, 2001). With few *Diporeia* present, the fish fed on low-quality food items such as zebra mussels and sphaeriids. Similar declines in lake whitefish condition were reported in Lake Ontario after *Diporeia* populations decreased (Hoyle et al, 1999).

Although we know that *Diporeia* is declining in Lake Huron (Nalepa unpublished), little is known about the corresponding responses of lake whitefish in the lake. This fish species is the most important commercial fish in Lake Huron. Harvest in the lake is approximately 4 million pounds per year, which is more than the total of the sport and commercial harvest of all other species combined. A decline in condition would have economic implications as harvest and marketability will decrease. Lake whitefish in poor condition could also experience poor reproductive success, causing a decline in recruitment to the fishery. Understanding diet patterns and bioenergetics of lake whitefish in Lake Huron was recently identified as a top-priority research item for funding by the Lake Huron Technical Committee, under the auspices of the Great Lakes Fishery Commission.

We propose to examine the seasonal depth distribution and diet of lake whitefish in Lake Huron off Alpena, Michigan. Lake whitefish will be collected at two to three stations in water depths 15-75 m in spring, summer, and fall. Fish will be collected using multi-panel monofilament gill nets (square mesh size 2-5.5 inch) set on the bottom overnight. All fish collected will be measured, weighed, a scale sample will be taken for age analyses and the stomach will be removed and frozen. The fish body will be retained for caloric density analyses. In the laboratory, stomachs will be dissected and prey items identified and counted. Prey lengths of whole organisms will be measured using a computer image analysis system (Image-Pro 3.0). Prey length will be converted to dry mass using length-weight regressions or species-specific mean weights. Diet will be reported as frequency of occurrence (percent of fish containing a given prey type), and percent of the total calculated dry-weight. Benthic invertebrates will be collected at the same sites as the fish collections. All organisms will be picked and counted and the size of *Diporeia* will be determined.

In addition to examining fish collected off Alpena, we have been offered the opportunity to examine the diet of lake whitefish collected from other areas of Lake Huron. As part of their whitefish assessment programs, the Ontario Ministry of Natural Resources (Lloyd Mohr is contact) regularly collects fish along the eastern shoreline (Ontario waters), and the Michigan Department of Natural Resources (Jim Johnson is contact) collects fish along the western shoreline (Michigan waters). These agencies will provide the fish, and we will measure the same variables as for fish collected off Alpena. Benthic invertebrate samples will be collected at the same sites where the fish were collected. We thus will have information on lake whitefish diet and condition from areas with varying densities of *Diporeia.*

## Accomplishments

*Determine the Rate of Diporeia Decline.* Prior to this project, in 2000 we conducted a benthic survey in the main basin of Lake Huron to document densities of *Diporeia* and other macroinvertebrates. Although spatial coverage was good, with 66 sites sampled lake-wide, no sites were located in Georgian Bay or North Channel. To

accomplish the goal of complete lake coverage, arrangements were made with Environment Canada to collect benthos samples in Georgian Bay and North Channel during their surveillance cruise in August 2002. During this cruise, benthos samples were collected in triplicate at 17 sites in Georgian Bay and at 13 sites in North Channel. Over this reporting period, all organisms in these samples were picked, sorted by major taxa, and counted. To examine population trends of *Diporeia* in these two lake areas, densities found in 2002 were compared to densities found in 1973 (Loveridge and Cook, 1976). The 1973 survey was the most recent survey conducted in Georgian Bay and North Channel prior to our sampling in 2002. Overall, densities of *Diporeia* in 2002 were similar to, or greater than, densities found in 1973 (Table 1). The only exception was at the 31-50 m depth interval in North Channel where *Diporeia* densities were lower. Thus, based on these data, *Diporeia* populations appear to be stable in both Georgian Bay and North Channel. This finding contrasts to trends found in the main basin. The 2000 survey showed that densities of *Diporeia* in shallower areas of the main basin (less than 50 m water depth) were significantly lower than densities found in 1972, and that *Diporeia* was no longer present in the southern portion of the lake (Nalepa, unpublished data).

| Depth Interval | Georgian Bay | | North Channel | |
|---|---|---|---|---|
| | 1973 | 2002 | 1973 | 2002 |
| < 30 m | 771 $\pm$ 286 (17) | 1,690 $\pm$ 827 (3) | 1,645 $\pm$ 248 (23) | 2,054 $\pm$ 705 (5) |
| 31-50 m | 1,579 $\pm$ 278 (24) | 1,456 $\pm$ 595 (5) | 2,593 $\pm$ 2,134 (23) | 892 $\pm$ 401 (6) |
| 51-90 m | 1,774 $\pm$ 137 (52) | 1,684 $\pm$ 306 (9) | 3,068 $\pm$ 513 (7) | 3,348 $\pm$ 43 (2) |

Table 1. Mean ($\pm$ SE) density (No./$m^2$) of *Diporeia* at various depth intervals in Georgian Bay and North Channel, Lake Huron in 1973 and 2002. The 1973 data was taken from Loveridge and Cook (1976). The number of sampling stations is given in parenthesis.

In addition to processing samples collected throughout Georgian Bay and North Channel in August 2002, we also counted, picked, and sorted benthic organisms in samples provided by the Ontario Ministry of Natural Resources (OMNR) as part of their ecosystem monitoring program. The program was initiated in 2000 with the purpose of monitoring trends in major food web components, including benthic macroinvertebrates. Each year, benthic samples were collected at various depths (20, 40, 60, 80, 90-100 m) along a transect near Cape Rich, which is on the southern shoreline of Georgian Bay. Densities of the major benthic taxa in 2000-2002 are given in Table 2. Of concern is the obvious decline in *Diporeia* at all depths over this period. Densities found at the Cape Rich transect in 2002 were far lower than mean densities found at other sites of similar depth (see Table 1). Reasons for this discrepancy are not clear at this time, but population declines can be very localized (Nalepa et al. 1998).

*Examine Diet Patterns in Lake Whitefish*. To supplement our examination of seasonal changes in diet patterns of lake whitefish off Alpena, Michigan, additional fish were obtained from the Michigan Department of Natural Resources (MDNR), U.S. Fish and Wildlife Service (USFWS) and OMNR that were collected in 2002. The former two agencies provided fish that were collected along the Michigan shoreline north of Alpena, Michigan, while the latter agency provided fish from the Canadian shoreline south of Goderich, Ontario and in Georgian Bay (Cape Rich transect as given above). This project proposed to examine stomach contents of these extra fish

| Depth (meters) and Year | Taxa | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | *Diporeia* | Oligochaeta | Chirono-midae | Sphaeri-idae | Gastropoda | *Hexagenia* | *Dreissena polymorpha* | *Dreissena bugensis* |
| 20 m | | | | | | | | |
| 2000 | 315 | 2794 | 210 | 486 | 10 | 277 | 2241 | 0 |
| 2001 | 38 | 601 | 181 | 286 | 0 | 734 | 191 | 0 |
| 2002 | 19 | 686 | 114 | 67 | 76 | 982 | 1649 | 48 |
| 40 m | | | | | | | | |
| 2000 | 1144 | 467 | 67 | 153 | 0 | 0 | 0 | 0 |
| 2001 | 1516 | 277 | 219 | 372 | 0 | 0 | 10 | 0 |
| 2002 | 524 | 477 | 67 | 572 | 0 | 0 | 10 | 0 |
| 60 m | | | | | | | | |
| 2000 | 2174 | 2136 | 105 | 0 | 0 | 0 | 10 | 0 |
| 2001 | 791 | 524 | 0 | 10 | 0 | 0 | 0 | 0 |
| 2002 | 48 | 524 | 38 | 19 | 0 | 0 | 0 | 0 |
| 80 m | | | | | | | | |
| 2000 | 1805 | 992 | 219 | 0 | 0 | 0 | 0 | 0 |
| 2001 | 1468 | 86 | 68 | 124 | 0 | 0 | 0 | 0 |
| 2002 | 86 | 324 | 29 | 86 | 0 | 0 | 0 | 0 |
| 92-100 m | | | | | | | | |
| 2000 | 1707 | 734 | 248 | 76 | 0 | 0 | 0 | 0 |
| 2001 | 1182 | 744 | 68 | 343 | 0 | 0 | 0 | 0 |
| 2002 | 114 | 896 | 0 | 143 | 0 | 0 | 0 | 0 |

Table 2. Mean density (No./$m^2$; n=2) of major macroinvertebrate taxa in 2000-2002 at various depths along a transect off Cape Rich, Ontario, southern shoreline of Georgian Bay.

and determine diet patterns. During this reporting period, stomach contents of these fish were examined and preliminary analysis of adult fish ( greater than 350 mm) is given in Table 3. Diet was highly variable, but several aspects of the diet analysis are noteworthy. In fish from all areas except Georgian Bay, *Dreissena* (both zebra and quagga mussels), comprised a considerable portion of whitefish diet. On the other hand, *Diporeia* was found in the diet of fish from only one area (OMNR-8). Historically, *Diporeia* comprised up to 81 percent of whitefish diet in Lake Huron (Ihssen et al, 1981). These diet changes likely reflect the recent decline of *Diporeia* and the expansion of *Dreissena* populations in nearshore regions of the lake (Nalepa et al, 2003). Since *Diporeia* is rich in lipids and calories compared to *Dreissena*, trends in these two organisms are likely a major factor in the general decline of whitefish condition in the lake (Lloyd Mohr, OMNR, personal communication). Also, note the presence of *Hexagenia* in the diet of whitefish from Cape Rich (Table 3). *Hexagenia* is abundant in this portion of Georgian Bay (see Table 1).

| Taxa or Group | MDNR (n=58) | USFWS (n=17) | OMNR-5 Southhampton to Chief's Pt. (n=39) | OMNR-8 Bayfield to Goderich (n=11) | OMNR-19 Cape Rich, Georgian Bay (n= 6) |
|---|---|---|---|---|---|
| *Diporeia* | 0.0 | 0.0 | 0.0 | 22.0 | 0.0 |
| *Dreissena* | 21.9 | 70.1 | 18.0 | 55.0 | 0.0 |
| Gastropoda | 45.2 | 16.4 | 39.0 | 0.0 | 7.0 |
| Sphaeriidae | 21.7 | 0.0 | 0.0 | 0.0 | 0.0 |
| Chironomidae | 5.8 | 1.5 | 0.0 | 0.0 | 0.0 |
| *Hexagenia* | 0.0 | 0.0 | 0.0 | 0.0 | 20.0 |
| Fish | 3.3 | 12.6 | 21.0 | 0.0 | 0.0 |
| Zooplankton | 0.0 | 0.0 | 16.0 | 23.0 | 70.0 |
| Other | 2.0 | 0.0 | 6.0 | 0.0 | 4.0 |

Table 3. Diet of adult lake whitefish (greater than 350 mm) in various locations in Lake Huron. The MDNR and USFWS fish were collected along the Michigan shoreline from Alpena to the Straits of Mackinac, and the OMNR fish were collected along the Canadian shoreline at the location given. Values are the mean percentage wet weight. n = number of fish examined.

## Future Activities

A major benthic survey was completed for the main basin of Lake Huron in August 2003. All 66 sites sampled in 2000 were re-sampled along with an additional 16 sites that were not sampled in 2000. These additional sites are located in areas where whitefish were collected by collaborative agencies in 2002. The main purpose of the benthic survey is to determine the rate of *Diporeia* decline throughout the main basin from 2000 through 2003. Over the next six months, CILER research assistant Andrew Foley will be spending most of his time counting D*iporeia* in these samples. We expect to again receive whitefish for diet analysis from MDNR, USFWS, and OMNR. With two years of data, we will then proceed to examine whitefish condition relative to diet in the various lake areas.

## Publications

Price, H., S.A. Pothoven, M.J. McCormick, P.C. Jensen and G.L. Fahnenstiel. 2003. Temperature influence on commercial Lake Whitefish harvest in eastern Lake Michigan. *Journal of Great Lakes Research* 29(2): 296-300.

## Significant Interactions

Lloyd Mohr, Ontario Ministry of Natural Resources, provided whitefish from eastern Lake Huron for diet analysis. Jim Johnson, Michigan Department of Natural Resources, provided whitefish from northeastern Lake Huron for diet analysis. Discussions were held with Jeff Schaeffer, US Geological Survey Great Lakes Science Center, concerning data sharing.

# CA4/IV-10: Inventories of PCBs in the Depositional Sediments of Lake Michigan

*Principal Investigators: Brian J. Eadie, Great Lakes Environmental Research Laboratory and John A. Robbins, Great Lakes Environmental Research Laboratory*

NOAA Strategic Goal 1

## Background

In aquatic systems, rapid and efficient sorption and settling remove contaminants from the water column into the sediments. Large episodic events resuspend and transport materials from temporary sedimentary sinks to more permanent sinks with a small fraction becoming incorporated annually into the sediments of the depositional basins. Resuspension and transport of the large inventories of nutrients and contaminants deposited over the past few decades presently results in much greater fluxes to the water column than from all external inputs. The focus of this effort is to measure inventories of PCBs in Lake Michigan sediments and use these data in lake-scale mass balance models.

## Research Plan

Between 1994 and 1996 a total of 55 sediment box cores were collected from the depositional regions of Lake Michigan. Subcores from each of the box cores were sectioned in 1 cm intervals to allow a detailed geochronology of sediment deposition. The vast majority of chemical analyses have been completed on these samples, including $^{137}Cs$, $^{210}Pb$ (geochronology), and *surface* concentrations of organic carbon, carbonate, nitrogen, phosphorus, silica, PCBs, PAHs, and some pesticides. A subset has also been analyzed for the suite of elements measured by neutron activation analysis. The data are in near final form, needing some minor editing to improve ease-of-use and a small number of reruns for values that fail various QA/QC checks.

At each coring site, a low-resolution core was collected for possible later analyses of contaminant inventories. Each of these low-resolution cores had a high-resolution companion from the same box core that has been analyzed and its geochronology established.

In this project, Sander Robinson, a CILER research associate, will use the geochronological information to determine the depth position of the 1900-1920 horizon. All sectioned core samples from above that horizon will be carefully composited to create a single sample from each site that represents all sediments deposited from 1900-1920 through the mid 1990s – the entire period of loading for PCBs (marketed by Monsanto from 1930-1977). Each composite sample will be extracted and analyzed for congenor-specific PCBs. A careful interpretation of these data will allow us to calculate the total amount of PCBs stored in Lake Michigan and the patterns of their deposition will provide information on their sources and transport. Figure 1 illustrates the locations of all sediment samples collected; we will focus on box cores where PCBs are accumulating.

## Activities

Compositing of the samples has been completed and laboratory analyses of congenor-specific PCB concentrations are ongoing. The results will be used by several program collaborators in their calculations of the cycling of PCB, and other constituents within Lake Michigan. Our results will be published and provide best ever estimates of inventories of PCBs in Lake Michigan as well as being used to constrain mass balance and sediment transport models.

## Publications

Eadie, B.J. and J.A. Robbins. 2004. Composition and accumulation of Lake Michigan sediments. In The State of Lake Michigan, M. Muniwar and T. Edsall, eds., (in press).

VanHoof, P.L. and B.J. Eadie. 2002. Polychlorinated biphenyls and trans-nonachlor in Lake Michigan sediments. Chapter 6 in Results of the lake Michigan Mass Balance Study: Polychlorinated Biphenyls and Trans-Nonachlor Data Report. December 2001, USEPA Great Lakes National Program Office, 905R-01-011.

Eadie, B.J. 1995. Trap sample splitting (wet). In Lake Michigan Mass Balance Study (LMMB) Methods Compendium Volume I (http://www.epa.gov/glnpo/lmmb/methods/spliter.pdf).

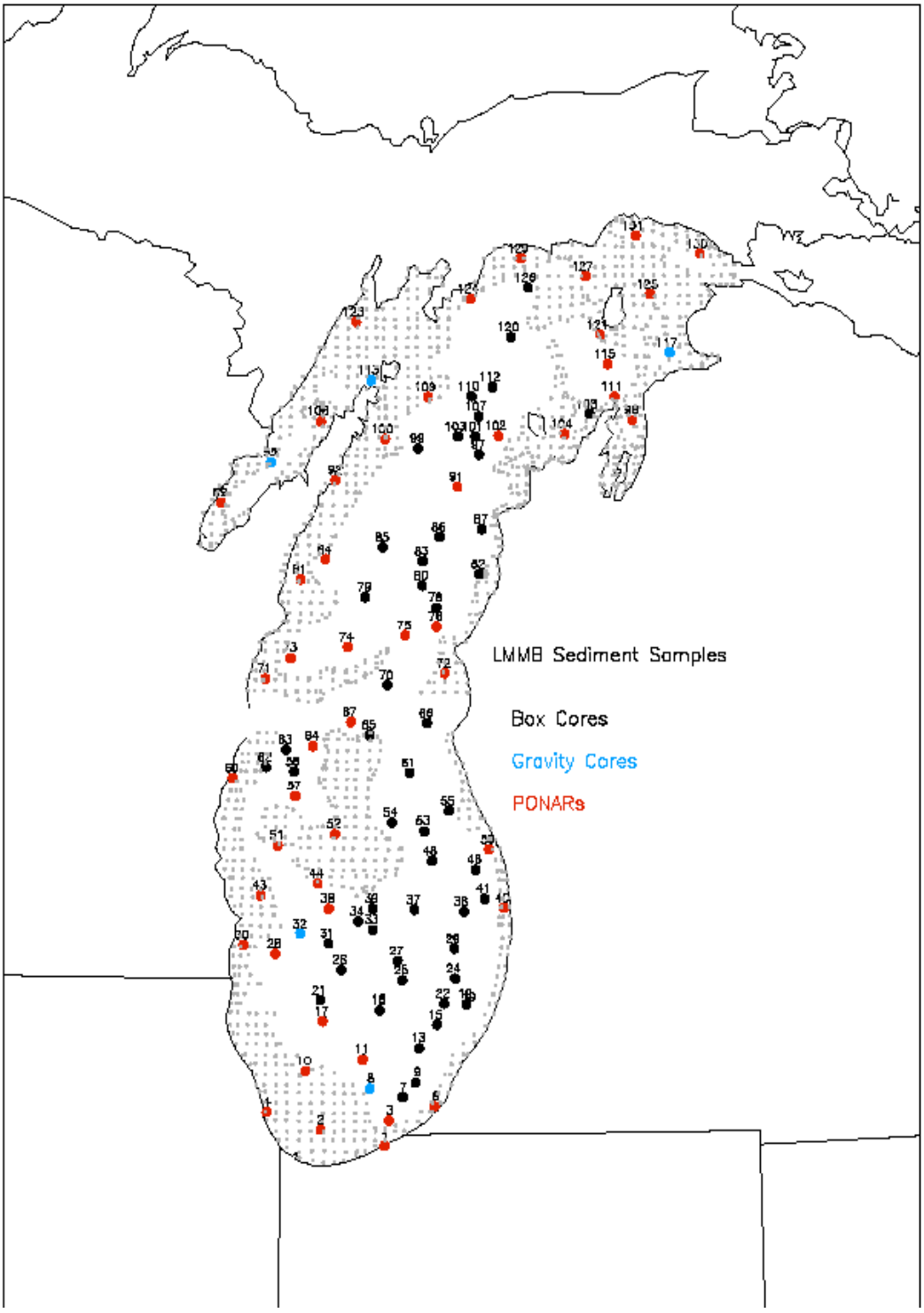


Figure 1. Illustration of locations where sediments were collected, with focus on PCB accumulation at box cores sites.

## Presentations

Eadie, B.J., J.A. Robbins, T.H. Johengen, D.N. Edgington, P. VanHoof, N.R. Morehead and M.B. Lansing. 2003. Distribution and recent accumulation of nutrients and contaminants in the sediments of Lake Michigan. International Association for Great Lakes Research. June. Chicago, Illinois.

Robbins, J.A., B.J. Eadie, D.N. Edgington, N.R. Morehead and R. Rood. 2003. Fallout radionuclide studies and Lake Michigan Mass Balance modeling. International Association for Great Lakes Research. June. Chicago, Illinois.

Eadie, B.J., D. Beletsky, J.A. Robbins, D. Schwab and T. Johengen. 2002. Advances in our understanding of sediment-water exchange and sediment transport from the Lake Michigan mass balance and episodic events programs. Plenary presentations at the 4th International Lake Ladoga Symposium. September. Velikiy Nvgorod, Russia.

Eadie, B.J., J.A. Robbins, D.J. Schwab, P. VanHoof, K. Hornbuckle and T.H. Johengen. 2001. Advances in our understanding of sediment-water exchange and sediment transport from Lake Michigan mass balance and episodic events programs. Lake Michigan: State of the Lake Conference. November 6-7. Muskegon, Michigan.

## Significant Interactions

Seminars have been given to the USEPA, the International Joint Commission, the Great Lakes Federation, and in several public fora.

## CA4/IV-11: Fish Recruitment Disruption Due to Invasive Predator Cladocerans: Density and Behaviorally Mediated Effects.

*Principal Investigator: Scott Peacor, Michigan State University*

NOAA Strategic Goal 1

The objectives of this first year were to establish a protocol and set-up to test behavioral responses of Great Lakes zooplankton to their predators, in particular the invasive species *Bythotrephes*, and to implement this protocol. Both objectives have been successfully met. We have found that our set-up and protocol are good tools to test behavioral responses of zooplankton to predators. We have found, for the first time, that Great Lakes zooplankton respond strongly to predators. In particular, we have found that several species of cladocerans and two copepod species respond to both invertebrate and fish predators. Of particular interest is that a common zooplankton, *Daphnia mendotae*, which is a resource of YOY fish, responds strongly to the invasive cladoceran *Bythotrephes*. Further, and perhaps surprisingly, it responds qualitatively different to *Bythotrephes* than it does to another invertebrate predator, *Mysis*. While these are exciting results that will lead to publications, much of our work has focused on developing the protocol, for example, establishing the importance of resource level and prey density in our experiments.

## Publications

Peacor, S.D., K.L. Pangle and H.A. Vanderploeg. 2004. Behavioral response of Lake Michigan *Daphnia galeata mendotae* to *Mysis*. *Journal of Great Lakes Research* (submitted).

## Significant Interactions

We are consulting with Dr. Ora Johannsson, Fisheries and Oceans Canada, on our laboratory research. In addition, we have initiated a collaborative project in which we are analyzing her data collected in Lake Erie to search for indirect effects caused by *Bythotrephes* through induced change in prey behavior. We are collaborating closely with Dr. Hank Vanderploeg, NOAA/Great Lakes Environmental Research Laboratory, on this project and on a survey project on fish and fish prey off the coast of Muskegon in Lake Michigan.

## Additional Funding

Fish recruitment disruption due to invasive predator cladocerans: density and behaviorally mediated effects, Great Lakes Fishery Commission, $173,657 (2004-07).

## Student Participation

This project is funding Kevin Pangle, a Michigan State University graduate student in the Department of Fisheries and Wildlife. Mr. Pangle successfully defended his thesis proposal in May 2004 entitled, "Trait-mediated indirect interactions between invasive predatory cladocerans and age-0 fish in Lake Michigan."

## CA4/IV-13: Changes in Diporeia Populations in the Great Lakes and Lake Champlain

*Principal Investigator: Thomas Nalepa, NOAA/Great Lakes Environmental Research Laboratory*

NOAA Strategic Goal 1

The relationship between declines in the benthic amphipod *Diporeia* and body burdens of attached epibionts was examined at three sites in southeastern Lake Michigan. Samples were collected on a monthly basis. *Diporeia* populations at the three sites were in various states of decline. Epibionts associated with *Diporeia* were examined using scanning electron microscopy (SEM). Overall, the most frequently occurring epibionts were *Peritrichia* (*Epistylidae* and *Lagenophryidae*) and *Suctoria*. Mean number of epibionts per individual *Diporeia* ranged from 39 to 300. Despite contrasting trends in *Diporeia* populations at the three sites (severe decline, no decline, severe decline at time of sampling), the number, type, and body location of epibionts found attached to *Diporeia* were generally similar at the three sites. Based on these findings, it can be concluded that epibionts were not likely the direct cause of declines in *Diporeia* populations.

## Publications

Foley, A.J.III, T.F. Nalepa, G.K. Walker and M.J. McCormick. 2004. Epibionts associated with *Diporeia* spp. from Lake Michigan. *Verh. Internat. Verein. Limnol.* (submitted).

Nalepa, T.F., D.L. Fanslow and A.J. Foley III. 2004. Spatial patterns in population trends of the amphipod *Diporeia* spp. and *Dreissena* mussels in Lake Michigan. *Verh. Internat. Verein. Limnol.* (submitted).

## Presentations

Foley, A.J.III, T.F. Nalepa and G.K. Walker. 2004. Epibionts associated with *Diporeia* spp. from Lake Michigan. Societas Internationalis Limnologiae (SIL), XXIX Congress. August. Lahti, Finland.

Nalepa, T.F., Fanslow, D.L. and A.J. Foley III. 2004. Characteristics and potential causes of declines on the deepwater amphipod *Diporeia* spp. in the Great Lakes. August. Lahti, Finland.

## Significant Interactions.

Dr. Gretchen Messick, Center for Coastal Environmental Health and Biomolecular Research, Oxford, Maryland – interactions, discussions related to epibionts associated with amphipods. Dr. Bozena Kiziewicz, Department of General Biology, Medical University, Bialystok, Poland – interactions concerning fungi attached to amphipods. Dr. Kevin Keuhn, Department of Biology, Eastern Michigan University, Ypsilanti, Michigan – discussions concerning fungi attached to amphipods. Dr. Glenn Walker, Department of Biology, Eastern Michigan University, Ypsilanti, Michigan – interactions, discussions on the use of SEM and identifying epibionts. Dr. Igo Dovgal, Department of Biology, Kiev University, Kiev, Russia – identification of suctorians.

## CA4/IV-14: Dynamics of Sculpin Fishes Found in Lake Michigan

*Principal Investigator: Stephen Brandt, NOAA/Great Lakes Environmental Research Laboratory*

NOAA Strategic Goal 1

We investigated habitat selection by slimy sculpin (*Cottus cognatus*) and deepwater sculpin (*Myoxocephalus thompsoni*), a pair of benthic fishes in Lake Michigan that are reported to be distributed discontinuously along a depth gradient. Slimy sculpin are common between 35 and 85 m, whereas deepwater sculpin are mainly found at depths > 75 m. We examined the hypothesis that habitat selection in these fish is driven mainly by the abundance and distribution of their principle food resources and interspecific differences in foraging ability. Field work conducted in 2000 and 20001 indicated that the benthic amphipod *Diporeia* was the primary prey of slimy sculpin. *Diporeia* and second invertebrate, the opposum shrimp *Mysis relicta*, were both important foods for deepwater sculpin. Since the distributions of deepwater sculpin and *Mysis* overlapped, we hypothesized that deepwater sculpin may be

more successful at capturing *Mysis* than slimy sculpin. Laboratory experiments showed that foraging success of slimy sculpin was highest with *Diporeia* and midge larvae, and the depth distribution and diets of slimy sculpin in the field corresponded with the distributions of these prey groups. Deepwater sculpin foraging success also was highest with *Diporeia*, but deepwater sculpin were not more successful than slimy sculpin at capturing *Mysis* in laboratory experiments. Deepwater sculpin distributions in the field were responsive to changes in the abundance and distribution of *Diporeia*, but changes in the distribution of this invertebrate did not explain the sudden increase in the abundance of deepwater sculpin that typically occurs at 70-80 m. It is possible that competition between these two sculpin species influences their distributions, but we were unable to demonstrate competitive interactions. Results from both the laboratory experiments and field studies are being formulated into a foraging model to determine if sculpin habitat selection can be predicted on the basis of energetic considerations.

## Publications

Hondorp, D.W., S.A. Pothoven and S.B. Brandt. 2004. Influence of *Diporeia* density on the diet composition, relative abundance, and energy density of planktivorous fishes in southeast Lake Michigan. *Transactions of the American Fisheries Society*. (In Press.)

Madenjian, C.P., D.W. Hondorp, T.J. DeSorcie and J.D. Holuszko. 2004. Sculpin community dynamics influenced by interactions with non-sculpin fishes. Under review by the *Journal of Great Lakes Research*.

## Presentations

Hondorp, D.W., S.A. Pothoven, S.B. Brandt and C.P. Madenjian. 2004. Factors influencing habitat selection in Great Lakes Sculpin. 134th Annual Meeting of the American Fisheries Society. August 22-26. Madison, Wisconsin.

## Significant Interactions

Our main interaction had been with scientists at the USGS Great Lakes Science Center, who provided laboratory space for our sculpin foraging experiments as well as provided information on long-term sculpin dynamics in Lake Michigan. This interaction has produced one manuscript, with at least two others in the planning/writing phase.

## Student Participation

Darryl W. Hondorp, PhD in natural resources and environment, University of Michigan, expected completion date April 2005. Mechanisms of depth segregation in Lake Michigan sculpin (*Cottidae*).

## CA4/IV-15: Distribution and Biomass of Dreissenid Mussels in Western Lake Erie

*Principal Investigator: Stephen Lozano, NOAA/Great Lakes Environmental Research Laboratory*

NOAA Strategic Goal 1

### Project Goal

This research will provide a statistically valid and precise estimate of lakewide and habitat-specific dreissenid abundance and biomass (defined by depth and substrate type) of the western basin of Lake Erie in 2004.

### Rationale

The trophic structure of Lake Erie has seen dramatic changes over the past 20 years. Lake Erie continues to be the most rapidly changing of the Great Lakes, reflecting the successes of remediation activities and the expression of both ongoing and novel stresses. The most significant events have related to amelioration of carbon and nutrient loadings to the lake. However, establishment of non-native exotic species, particularly dreissenid mussels, has resulted in substantial reallocation of biomass and redirection of energy flow. There is increasing evidence that energy flow patterns in Lake Erie have changed to reflect increasing importance of benthic processes to overall trophic functioning. Phenomena typically associated with increasing eutrophication (rising spring total phosphorus concentrations, episodic blooms of blue-green algae, development of extensive filamentous algal mats at shorelines, recurrent hypoxia in the bottom waters of central Lake Erie) are suspected to be either direct or indirect consequences of these altered trophic processes. The energy and nutrient pathways coupling the benthic and pelagic communities of Lake Erie are only partially understood, and few quantitative data on benthic-pelagic coupling exist to validate or calibrate models or to quantify mechanisms and relationships.

### Research Accomplishment for 2004

- We collected benthic samples in the western basin of Lake Erie at 70 offshore locations. All dreissenids collected in the samples were measured for size and biomass.
- We conducted video and acoustic surveys along transects that parallel samples collected by Environment Canada divers. A total of twenty tracks of 5 km were surveyed.
- A QTC VIEW (borrowed from UW-Milwaukee) seabed classification system was deployed on all tracks. Bathymetric data was overlaid on an airborne IR image. Raw complex waveform data at frequencies of 50 kHz and 200 kHz were logged. Classification results were plotted as a classified vessel track. The data will be interpolated to generate a full coverage plot and class colors will be identified using a similar acoustic class – similar color scheme.
- Video images were obtained from our underwater camera system. The videotapes have been analyzed at NOAA/GLERL for number and size of

mussel patches. Individual frames were used to create the photomosaic layer for the sediment classification work.

## Significant Interactions

Field work associated with the project involved direct collaboration with scientists from Environment Canada, Ontario Ministry of Fisheries, and the University of Guelph.

## Student Participation

One student was supported through the NOAA Great Lakes summer fellowship program to participate in the project. The student spent three months this past summer working on components of all of the tasks defined above.

## REMOTE SENSING OF LARGE LAKE AND COASTAL OCEAN DYNAMICS

Research by CILER Fellows in the area of remote sensing and coastal ocean dynamics builds upon an enormous base of expertise existing within the Great Lakes basin. In addition, large lakes and coastal oceans offer unique opportunities to further the science of remote sensing of surface and near surface dynamics. In the case of large lakes, remote sensing of the temperature field provides a direct measure of the density field. Hence, this one-to-one correspondence, which does not exist in the salt-water environment, provides new and exciting clues to the interrelations between physical, biological, and chemical processes. Remotely sensed environmental data for near real-time observation of the Great Lakes support a variety of research activities and resource management needs. For example, the rapid formation and extensive existence of ice throughout the Great Lakes basin creates a serious need to more fully utilize the capabilities of remote sensing to foster and promote safe navigation. Furthermore, the well-developed methods of terrestrial remote sensing provide excellent mechanism from which to analyze change brought about by society, environmental conditions, and land-water interactions. These capabilities utilized in a data fusion framework will provide the catalyst for the formation of the next generation of numerical predictive models for Great Lakes and coastal ocean dynamics.

### CA4/V-02: COASTWATCH OPERATIONS

*Principal Investigator: George A. Leshkevich, Great Lakes Environmental Research Laboratory*

NOAA Strategic Goal 1

CoastWatch is a nationwide National Oceanic and Atmospheric Administration (NOAA) program, within which, the Great Lakes Environmental Research Laboratory (GLERL) and CILER function as the Great Lakes regional node. In this capacity, GLERL and CILER obtain, produce, and deliver environmental data and products for near real-time observation of the Great Lakes to support environmental science, decision making, and Great Lakes research activities. These benefits are achieved by providing Internet access to near real-time and retrospective satellite observations, *in situ* Great Lakes data, and derived products to federal, state, and local agencies, academic institutions, and the public via the Great Lakes CoastWatch web site http://coastwatch.glerl.noaa.gov. The goals and objectives of the Coast-Watch Great Lakes Program directly support NOAA's statutory responsibilities in estuarine and marine science, living marine resource protection, and ecosystem monitoring and management. Great Lakes CoastWatch data are used in a variety of ways including monitoring of algal blooms, plumes, ice cover, and water temperatures, two and three dimensional modeling of Great Lakes physical parameters such as wave height and currents, damage assessment modeling, research, and for educational and recreational activities.

Utilities such as JAVA based interactive retrieval of physical parameters such as surface temperature, ice cover, winds, and bottom depth at a given location enhance the accessibility and utility of Great Lakes CoastWatch data. A new image product, GOES SST, has recently been added to the suite of products. The images are derived from the Geostationary Operational Environmental Satellite (GOES) and represent a three hourly composite of water surface temperature at a 4-km resolution. In addition, a new image viewer and analysis utility (CDAT- CoastWatch Data Analysis Tool) for CoastWatch and other images has been made available on the Great Lakes CoastWatch website. Windows and UNIX versions are available for download.

This project focuses on research and applications development utilizing CoastWatch imagery and imagery from new satellite sensors such as synthetic aperture radar (SAR) for ice classification and mapping. In addition, ocean color sensors such as the Sea Viewing Wide Field-of-View Sensor (SeaWiFS) and/or MODIS will be used to produce ocean color (chlorophyll) products. These products will enhance the CoastWatch Great Lakes product suite by developing regional products and applications for the Great Lakes, and will contribute to the operational responsibilities of agencies such as the US Coast Guard and the National Weather Service.

## Accomplishments

Research collaborations conducted under this project have led to the development of the following Great Lakes regional remote sensing products:

- Great Lakes Surface Environmental Analysis (GLSEA) – daily composite (5 day running mean) cloud free water surface temperature chart with ice cover overlay during the winter season derived from the National Ice Center Great Lakes Ice Analysis Charts.
- Reflectance (Turbidity) Product – This product is derived from Ch. 1 and Ch. 2 AVHRR data. Used for detection/monitoring of plumes and blooms.
- Histogram Equalized Ch.1 – This product is derived from Ch. 1 AVHRR data. Used for better ice detection.
- Statistics - This product (derived from the GLSEA) compares average lake-wide surface temperatures for a lake for period of record or for all lakes for a particular year (for period of record).
- Animations – this product provides animations (last 365 day and calendar year) of the temperature cycle on the Great Lakes derived from the GLSEA.
- RADARSAT SAR - imagery (subset by Lake)
- NOAAPORT- near real-time in situ meteorological data from buoys, CMAN, shore, and ship reports. This data helps in the interpretation of the remotely sensed data.
- Nowcast Winds – produced by the Great Lakes Coastal Forecasting System.

Additional Great Lakes regional satellite products under development include:

- Scatterometer Winds – for the Great Lakes derived from QuikSCAT.

- Scatterometer Ice Mapping – for the Great Lakes derived from QuikSCAT
- SAR Ice Classification – for the Great Lakes derived from RADARSAT / ENVISAT.
- Chlorophyll – for the Great Lakes derived from SeaWiFS / MODIS.

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## Significant Interactions

Users access Great Lakes CoastWatch near real-time AVHRR and other satellite imagery, data, products, and utilities via the Great Lakes CoastWatch web site at http://coastwatch.glerl.noaa.gov. As of September 15, 2003 there were 1525 registered data users. As registration is no longer required to access Great Lakes CoastWatch data and products, web statistics are gathered to assess data usage for web site improvement. During the period July 1, 2004 – September 8, 2004, visitors to the CoastWatch Great Lakes web site have come from 64 different domains (such as .gov, .edu, .com, .mil etc.). During this period, the web site was visited 42,277 times, with 2.0% from .gov, 1.2% from .edu, 23.6% from .com, 1.1% from .mil, 0.6% from .us, 34.0% from .net, 1.0% from .org.

## Additional Funding

Funding for the CoastWatch related satellite SAR (Synthetic Aperture Radar) and ocean color projects are provided by NOAA/NESDIS and COP (Coastal Ocean Program).

## MARINE ENVIRONMENTAL ENGINEERING

The Great Lakes and coastal waterways of the United States have been threatened in recent times by many invasive (non-indigenous) species. The primary mode of introduction and transport of these foreign invaders resides in marine vehicles, structures and systems, associated with the water-bore segment of world trade. In addition, mechanisms for the handling of contaminated sediments, dredge spoils as well as accurate and automated methods of providing safe navigation are expected to provide many difficult technical problems related to the marine environment. As new problems are discovered, innovative and revolutionary marine environmental engineering solutions will be required. Research by CILER Fellows in this task includes engineering related to the design and production of a wide variety of vehicles, structures, and systems to operate successfully in the harsh and demanding marine environment and also includes engineering which supports the understanding and proper use of the marine environment.

### CA4/VI-02: BIOLOGICAL CHARACTERIZATION OR ASSESSMENT OF ANS INVASION RISK FROM NOBOB VESSELS

*Principal Investigators: Gary L. Fahnenstiel, Great Lakes Environmental Research Laboratory; Thomas H. Johengen, University of Michigan and David F. Reid, Great Lakes Environmental Research Laboratory*

NOAA Strategic Goal 1

#### Background

Global shipping moves roughly 80 percent of the world's commodities and is fundamental to world trade. As an unintended result of these shipping activities, numerous cases of nonindigenous species introductions have occurred worldwide. In total, 159 successful exotic species invasions have been documented in the Great Lakes, and 41 of these introductions are believed to have resulted from shipping activities. Furthermore, the rate of introductions has increased dramatically during the past few decades, with six new introductions occurring between 1984 and 1990 alone. While we need not belabor here the widespread and deleterious effects of the zebra mussel, we note that less conspicuous introductions also can wreak ecological and economic havoc. For example, 23 phytoplankton species have been introduced to the Great Lakes via shipping activities and large populations of one of these, *Stephanodiscus binderanus*, have caused significant water quality (taste and odor) problems in municipal water treatment facilities. Moreover, successful introduction of non-indigenous phytoplankton into the Great Lakes has contributed to the extirpation of native species via competition, a result with ramifications for the base of the food web.

While circumstances vary from ship to ship, the relatively small amount of water that remains in most NOBOB (NO Ballast On Board) vessels entering the Great Lakes, together with any residual sediment, potentially harbors nonindigenous organisms. Consider a tank holding 1500 metric tonnes of water when full. If only one percent of that volume is unpumpable, then up to 15 metric

tonnes of water would remain. Reflected across the numerous tanks each ship possesses, a significant tonnage of ballast water can remain on board. Indeed, a 1991 Canadian study of NOBOB vessels entering the seaway reported volumes of ballast residuals ranging from 59 to 468 tonnes, with an average of 158 tonnes. It is this phenomenon that makes critical our better understanding of NOBOB vessel operations on the Great Lakes. Concerns about NOBOB biopollution have risen from a position of relative obscurity a few years ago to one of the chief environmental concerns in the Great Lakes basin today. On average, less than 25 percent of the ocean vessels entering the Great Lakes contain declarable ballast water on board. In 1996, for example, of 538 ocean entries, only 38 (6.1 percent) were vessels "in ballast" and thus subject to ballast water exchange requirements. NOBOB vessels escape regulation under existing U.S. and Canadian federal, state, and provincial laws, yet their ballast tanks may retain residual volumes of unpumpable ballast water and may contain an accumulation of sediment representing numerous previous ballasting operations.

## Rationale

Considering that NOBOB ships now constitute the bulk of commercial ship traffic entering the Great Lakes, we propose to examine the possibility of invasions associated with their residual ballast water and sediment. We will evaluate the risk of invasions associated with ocean-going vessels entering the Great Lakes. Specifically, two interrelated objectives will be addressed:

1. Characterize phytoplankton communities present in NOBOB tanks.
2. Measure the effect of adding Great Lakes water as ballast to NOBOB tanks on germination and growth of nonindigenous phytoplankton species present in ballast residuals and on their potential release from ballast tanks.

## Accomplishments

Analyses of phytoplankton abundance and growth potential were completed for all samples collected in 2001 and 2002 including 55 wet sediment samples and two dry sediment samples. Dinoflagellate cyst represented zero to 80 percent of total between phytoplankton abundance (average = 24 percent). Almost all the samples contained at least one dinoflagellate species, with a maximum 13 species. A total of 35 cysts species were identified, and 20 species were repeatedly found in both years. Twenty five percent of these species are reported to be toxic species, and a PSP causing species *Alexandrium minutum* is the most common species which occurring in 33 percent our samples. All the dinoflagellate cysts identified in our study are non-indigenous, including at least three species that are common members of the Baltic Sea flora. Dinoflagellate cyst species were found less in flushed tanks than in non-flushed tanks. Further study of the relationship between cyst composition and management practices may help to identify a protocol for monitoring the efficiency of management practice.

Germination and growth experiments were completed for samples collected in 2001 and 2002, including 33 water samples and 57 sediment samples. Experiments were performed using four different freshwater and one saltwater culture media. In all experiments at least one of the freshwater treatments produced phytoplankton

growth from the residual material. However, there was tremendous variability in the growth potential of each sample among treatments, both in absolute response and the dominance of species.

Diatoms were the dominant species in almost all growth experiments. Twenty-five species of non-indigenous marine and freshwater diatoms have been identified from the 20001 samples. Germination of non-indigenous species was found in 50 percent of samples; most of these species (50 percent) can grow in Lake Michigan or Grand River water, indicating the potential for ballast tank residuals to be a source of viable non-indigenous phytoplankton species to the Great Lakes. Several non-indigenous species were found to grow in both freshwater and saltwater culture media, indicating their potential viability in ocean water exchange treatment.

The goal of objective 2 is to assess whether the biota (including resting stages) resident in ballast tank residual water and sediment can invade the Great Lakes under actual ship operating conditions. We assume that mature pelagic organisms from the residuals can and do become entrained in ballast water added in the Great Lakes and thus may be discharged.

A total of five different vessel voyages were examined for objective 2, one in each 2001 and 2002, and three in 2003. Germination experiments were completed for all of the samples from these voyages. Experiments were performed using freshwater culture medium (GL) and Lake Michigan water. Phytoplankton growth was minimum in Lake Michigan water, but growth was significant in GL medium. There was significant variability in the growth potential of samples collected from the harbor water where ships were ballasting and ballast samples taken at the initial and final time points of the voyages. Phytoplankton growth was significantly higher in final ballast samples than in the harbor water sample for the 2001 experiment. Furthermore, there were no marines species observed in the harbor and initial samples, but marine species accounted for about one percent in the final sample. For the 2002 trial, the growth of phytoplankton was similar between initial and final sampling time points. For the 2003 trials, growth was significantly different between harbor water, $T_0$ ballast sample, and $T_f$ ballast sample. The species composition analysis from these trials is under process.

Presentations

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## Significant Interactions

This project was funded by multiple sponsors that included the U.S. Coast Guard, NOAA, and U.S. EPA. In addition, the activities conducted within this project led to the development of a successfully funded research proposal submitted to the Great Lakes Protection Fund. These additional funds allowed us to extend the scope of work, increase the number of vessels sampled, and increase the breadth of analyses conducted on ballast tank residuals. This project involves the collaboration of researchers from GLERL, the University of Michigan, the University of Windsor, and Old Dominion University. Results described here represent activities completed under the supplemental project as well as the cooperative agreement project.

## CA4/VI-03: Application of Passive Acoustic Methods for Automatic Detection of Right Whales: Numbers and Distributions.

*Principal Investigator: Christopher W. Clark, Cornell University*

NOAA Strategic Goal 1

## Background and Rationale

The population of northern right whales in the western North Atlantic is highly endangered. Ship strikes and fishing gear entanglements have lead to an increase in mortality. There is a critical need to monitor the number and distribution of whales throughout the year over large areas of their habitat. Efforts to survey right whales rely primarily on visual sightings of animals from vessels or aircraft. Photo identification and molecular genetic techniques have also advanced our understandings of calving rate, site fidelity, and population structure. Despite significant progress, the distribution of over half the right whale population is unknown for more than half the year. The primary reason for this large uncertainty is due to the limited capabilities of present methods to sample for right whales for long periods of time over large portions of their habitat. This sampling limitation is a result of the fact that all present methods rely on detecting whales when they are at the surface and visible to human observers. Therefore, a sampling method that is independent of visibility conditions and does not require animals to be at the surface could dramatically increase right whale detections and improve survey effectiveness.

Right whales produce distinctive sounds throughout the year. There is good evidence to support the assumption that passive acoustic methods can provide an effective mechanism for detecting and estimating the number of right whales (Clark 1982; 1983; Kraus 1991). Preliminary results from 2000 in Great South Channel and 2001 in Cape Cod Bay are very encouraging and indicate that the numbers and distributions of whales from acoustic detections were in general agreement with

results from the aerial surveys (Clark et al. 2000). Furthermore, preliminary results suggest that the probability of hearing a right whale call is very high if one listens for at least four hours and there is a right whale in the area. For Cape Cod Bay in 2001, over 40,000 right whale calls were detected in 25 days at three acoustic sampling stations, an average of over 260 calls/day/station.

Beginning in mid-December 2001 and continuing into early June 2002, with funding from the Northeast Consortium (NEC) program, Cornell Bioacoustics will deploy a total of 12 autonomous seafloor acoustic recorders in Cape Cod Bay (n=6) and across portions of the Great South Channel (n=6). These units, referred to as "pop-ups", will each record continuously for periods of two to three months. There will be two deployments in each area to provide coverage from early winter through late spring. Detections of right whale sounds are determined after the units are recovered and will be used to estimate whale numbers and distributions. In cases where three or more units are deployed in a geometric array, vocal right whales will be located and tracked. To specifically quantify and evaluate the relationship between acoustic detections and aerial survey sightings and the relationship between whale numbers and distributions and oceanographic variables we are collaborating with Drs. Brown and Mayo from the Center for Coastal Studies. The Cape Cod Bay and Great South Channel research includes collaborations with the Center for Coastal Studies (CCS) and the International Fund for Animal Welfare (IFAW), and a cooperative working relationship with the Massachusetts Division of Marine Fisheries (Dan McKiernan) and the Northeast Fisheries Science Center of the National Marine Fisheries Service (NMFS-NEFSC).

Additionally, in a pilot collaborative study with the Gulf of Maine Ocean Observing System project (GoMOOS), we will install an automatic real-time right whale detection system on one of the GoMOOS fixed buoys. By this process, counts of right whale calls will be relayed to shore stations and linked to a the GoMOOS website (http://www.gomoos.org) on an hourly basis, making it possible for viewers to receive simultaneous information on physical and biological oceanographic conditions as well as right whale acoustic activity.

The present pop-up scheme provides adequate spatial sampling during the December through June period. Because present plans are for only six pop-ups in Cape Cod Bay, we cannot fully cover the entire Cape Cod Bay (CCB) region. Likewise, because present plans are for only six pop-ups in Great South Channel (GSC), we can only install a single detection net across the region.

## Pop-Up Acoustic Recorder Technology

Based on the success of the various seafloor acoustic recorders developed by ocean engineers, we designed and fabricated our own units, which we refer to as “pop-ups”. These units[1] have now been used successfully in ocean depths ranging from 25 to 2200 m for durations of five to 40 days, on blue, fin, humpback, bowhead and

[1] A pop-up includes a programmable microprocessor, acoustic communications circuitry, a hard disk for data storage and batteries, all sealed in a single 17-inch glass sphere. An external hydrophone is connected to the internal electronics through a waterproof connector. Sound received by the hydrophone is digitized and stored on the hard disk. Recording can be continuous, or on any schedule programmed into the cpu. While a pop-up is deployed on the seafloor, an operator can communicate with it from a surface vessel via an acoustic transponder system. Using the transponder, the operator can query the pop-up about its operating status or command the unit to release its anchor and return to the surface for retrieval.

right whales. In the past two years, through various collaborations, we have had over 100 successful deployments of pop-ups.

The present generation of pop-ups can be deployed for periods of up to 65 to 70 days. The limiting factor on deployment length is battery life. The pilot project with GoMOOS in winter 2002 is a preliminary step in the process of developing smarter real-time right whale detection systems. A critical need is to design the next generation of pop-ups, which would allow deployments of up to a full year. These "smart" pop-ups would use new low-power, high-speed processors to run the signal detection software in real time and would save only those sounds that are the whale sounds of interest. By linking the detection results with telemetry systems, acoustic data on right whale presence and relative numbers could be available on a timely basis. The acoustic record would also provide information on ambient noise conditions and the presence or absence of vessel activities.

## Increased Spatial and Temporal Sampling

As described by Clapham (1999) and by the IWC (IWC 2000) the general characteristics of the right whale population distribution are known, but major gaps exist. As summarized in Clapham (1999), "The whereabouts of significant portions of the population are unknown for virtually all months of the year. Furthermore, recent genetic and sighting data indicate that, while many mature females consistently take their calves to the Bay of Fundy during the summer, a significant number do not."

Pop-ups offer a cost-effective and reliable mechanism for long-term monitoring of areas that are more difficult to sample. We will use Cornell's new research vessel operating out of the Isles of Shoals and also collaborate with IFAW, CCS, and the Massachusetts Division of Marine Fisheries (Dan McKiernan) for deployment and retrieval of these recorders.

## Activities

This project provided additional funding to augment and extend ongoing research funded through the NEC program. The specific objectives of the research are to apply passive acoustic methods to:

- Sample for the presence of right whales.
- Estimate the relative number of animals.
- Estimate the relative distribution of animals within several critical right whale habitats in waters around New England.

Validation of the passive acoustic method is being examined by statistical comparisons of acoustic results with those from visual surveys. These acoustic and visual results will also be integrated with physical and biological oceanographic data from surveys and remote sensing systems. These multiple data sets will be used to evaluate relationships between the number of whale calls detected, the number of whales seen, and oceanographic productivity when averaged over various time periods ranging from days to weeks.

In this project we emphasize that a multidisciplinary approach is the most effective means of elucidating the fundamental mechanisms underlying right whale distribution and fecundity, and therefore of implementing an effective conservation management policy. Present methods for monitoring right whales and estimating relative numbers over large portions of their habitat for long periods of time are inadequate. We are developing a passive acoustic research program to extend spatial and temporal sampling for right whales and as a means of developing a time-efficient mechanism for estimating right whale number and distribution in the northeast region of the North Atlantic.

In several workshops the suggestion has been made that passive acoustics could be used as a mechanism for an early warning system. We are convinced that passive acoustic detection of right whale sounds can be automated. The implementation of an early warning system would require a buoy equipped with a telemetry mechanism for transmitting data back to shore in real time. The recent Gulf of Maine Ocean Observing System (GoMOOS) project has installed a suite of moored buoys throughout the GoM region. With support from the NEC, Cornell is collaborating with the GoMOOS project to install a customized right whale acoustic detection units on one of the GoMOOS buoys. This buoy will deliver hourly right whale sound counts using onboard real-time detection technology and will store all acoustic detections on a resident hard drive. Detection count data will be telemetered back to the GoMOOS web site and made available on a near-real-time basis. Specific research activities for the project include:

- Deploy ten pop-ups in Cape Cod Bay from April 2002 through August 2002. These additional units will allow us to fully cover the Cape Cod Bay region so that acoustic and aerial coverage areas are essentially identical throughout the period when right whales are expected in the Bay. Units will be deployed in two arrays with four pop-ups per array (total of eight) and two separate units across the mouth of the Bay to the west of Race Point.
- Deploy ten pop-ups in Great South Channel from April through September 2002. This extra effort will nearly double the coverage in the Great South Channel. Pop-ups will be deployed in two east-west lines covering the northern and southern portions of the region, with units separated by about ten miles, thereby creating two east-west acoustic "nets."

## Findings

Autonomous, seafloor acoustic recorders, referred to as "pop-up", were built and deployed in the northern right whale's critical habitats of Cape Cod Bay and the Great South Channel, off Massachusetts. Pop-ups collected acoustic data from 21 November 2002 through 21 May 2003 in Cape Cod Bay, and from 3 April through 7 July 2003 in the Great South Channel. Acoustic detections of right whale contact calls were compared to aerial survey sightings (Dr. Moira Brown, Center for Coastal Studies), and zooplankton availability surveys (Dr. Stormy Mayo, Center for Coastal Studies) conducted during November 2002 through May 2003. A total of 900 days of acoustic data were collected and analyzed for right whale calls. Comparative analysis revealed reliable relationships between food availability, sighting index, and contact calls (see Figure 1 below). Results indicate that individual whales enter

and move through Cape Cod Bay starting in late fall and continuing throughout the winter and early spring, as if the whales are sampling for indications of high quality food patches. If the conditions are appropriate, individuals remain in the bay to feed, and if the conditions persist, animal concentration increases, and groups of animals engage in highly visible social activities that may be important for reproduction.

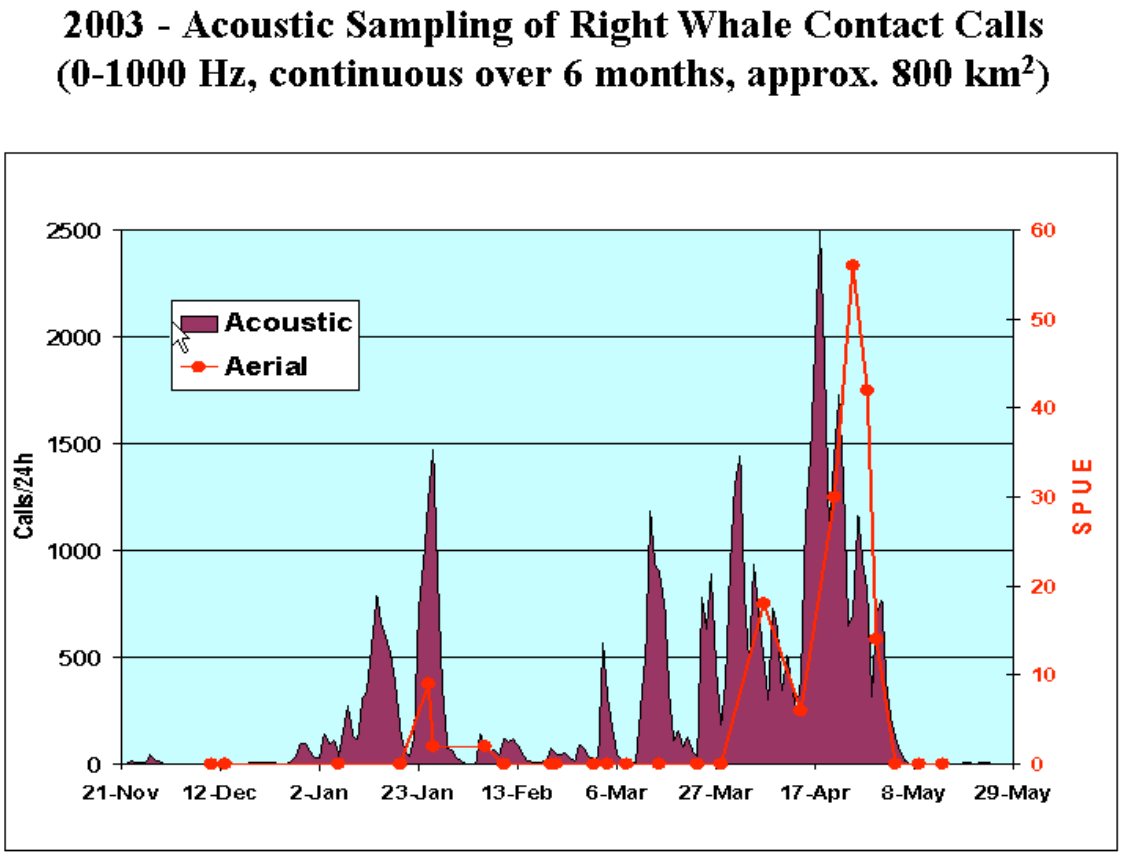


Figure 1. Daily counts of right whale contact calls in Cape Cod Bay as collected on pop-ups compared to whales sighted during standardized aerial surveys (data courtesy of Moira Brown, and Owen Nichols. SPUE analysis by Robert Kenney, where SPUE is sightings per unit effort)

## Publications

None yet. The data analyses from last year's efforts are just now near completion. A paper based on a previous year's effort was published in the *Proceedings of the Royal Society London* (April 2004).

## Presentations

The seasonal occurrence of northern Right Whales, *Eubalaena glacialis*, in a critical habitat: when, why and how many? Cape Cod Natural History Conference — 2004, March 2004, Barnstable Massachusetts.

The seasonal occurrence of northern Right Whales, *Eubalaena glacialis*, in a critical habitat: when, why and how many? Biennial Conference on the Biology of Marine Mammals, December 2003, Greensboro, North Carolina.

Right Whale acoustic detection. A Forum for North Atlantic Right Whale Conservation, November 2003, Woods Hole Oceanographic Institution, Woods Hole, Massachusetts.

Right whales acoustic monitoring results and progress toward real-time reporting. Right Whale Consortium-2003, November 2003, New Bedford, Massachusetts.

Right Whales in Cape Cod Bay: numbers and distributions from listening, looking and knowing about food. Right Whale Consortium – 2002, October 2002, New Bedford, Massachusetts.

## Significant Interactions

The success of this project is a result of a highly integrated and collaborative effort between multiple individuals from multiple institutions. CILER funding supplemented the addition of a remote acoustic monitoring technique for an endangered marine mammal species in a critical habitat where ongoing efforts have been directed at describing and documenting the distribution and relative abundance of northern right whales. This funding enabled continued growth in collaborations between scientists from Cornell University (Dr. Christopher Clark), the Center for Coastal Studies (Drs. Moira Brown and Stormy Mayo) and NOAA's NMFS-Northeast Fisheries Science Center in Woods Hole, MA (Dr. Phil Clapham and Mr. Tim Cole.) The rapid success of the project fostered collaborative initiatives with the Commonwealth of Massachusetts' Division of Marine Fisheries (DMF) staff (Mr. Dan McKiernan and Mr. Ed Lyman) that led to their support of fishermen who then helped directly with the project. This in combination with CILER funding allowed Cornell to extend acoustic spatial and temporal sampling into more remote areas than anticipated. For this offshore research we relied on the knowledge and skill of local fishermen, supported by DMF, who were invaluable in the successful deployments and recoveries of the oceanographic equipment. As a result of this project's overall success, the PI was able to secure further funding to advance the pop-up instrumentation technology into an auto-detection buoy technology (moored) that will have daily data uplinks to a website via cell phone. As a result, the concept of a near-real-time right whale detection and reporting scheme, as envisioned only four years ago, is about to become reality and will be implemented this coming fall in a critical habitat. This, therefore, represents a true example in which basic science combined with excellent engineering was rapidly transitioned into an application with tangible, practical benefits to people, endangered whales and their habitats.

## Student Participation

None. There was no graduate support under this grant. However, partially as a result of this research project, Ms. Ingrid Biedron, a 2003 graduate of Dartmouth College, was accepted into Cornell's Department of Neurobiology and Behavior as a student in Dr. Clark's lab. Ms. Biedron was awarded a three-year Department of

Defense Science Fellowship, and her research will focus on the potential impact of underwater noise on marine mammals.

## CA4/VI-05: Evaluating Aspects of the Ballast Tank Vector for Nonindigenous Species in the Great Lakes

*Principal Investigator: David Reid, NOAA/Great Lakes Environmental Research Laboratory and Thomas H. Johengen, University of Michigan*

NOAA Strategic Goal 1

### Project Rationale

The ballast tanks of commercial vessels are the primary vector for transporting aquatic invasive species (AIS) between coastal ecosystems. NOAA has responsibilities under Public Law 101-636 as amended through October 1996 to carry out programs and research to prevent the introduction of invasive species to coastal ecosystems of the United States. NOAA's Ballast Treatment Technology Demonstration Program is designed to explore alternative ballast treatment approaches aimed at eliminating or reducing the invasive species risk associated with ballast water and ballast tanks.

At present, ballast treatment approaches being tested by various groups in the United States and elsewhere fall into categories of physical removal (filtration; hydrocyclone or ultracentrifuge) and/or some form of biocide exposure (UV radiation, heat, ozonation, deoxygenation, and various chemical biocides). However, most tests of various treatment technologies and approaches have looked only at pelagic organisms, which will likely be the most easily treated. Resting stages, which may be sucked in from local sediments with incoming ballast water or produced by organisms entrained with the ballast water, have generally been ignored. The Great Lakes NOBOB (no-ballast-on-board) Program sampled the residual ballast material in 82 ballast tanks over the 2001-2002 Great Lakes shipping seasons. All residual samples contained varying concentrations of viable invertebrate resting eggs, ranging from $10^5$ to $10^6$ viable eggs $m^{-2}$ of residual sediment. Based on these results, resting eggs pose a potential invasion threat to both marine coastal areas and the Great Lakes. While various treatments are being developed and tested for removing or killing organisms in ballast water, resting stages have generally been overlooked, and due to their size range, will be difficult to physically remove from an incoming ballast water stream.

Coulatti et al (2003) summarized available overseas vessel traffic statistics for the Great Lakes for the period 1978-2000. However, they did not obtain any direct information about ballasting practices off these vessels while in the Great Lakes, and also had to make assumptions in order to classify each ship as either ballasted or NOBOB. Coast Guard records from 1991 through 1997 are now available that can be used to check the classifications assigned by Coulatti for ships entering during those years. In addition, the Great Lakes Environmental Research Laboratory is collecting ballast intake and discharge data from ships operating in the Great Lakes during the 2003 shipping season. These new data can be correlated and compared to the Coulatti database. Doing so will improve the accuracy of our understanding of vessel traffic and ballast patterns in the Great Lakes.

## Objectives

- Test the effect of various biocide treatments on the viability of a variety of zooplankton resting eggs obtained from natural populations, laboratory cultures, and ships of opportunity.
- Update, correlate, and re-evaluate existing data on the entry and ballasting characteristics of commercial vessels while in the Great Lakes.

## Research Plan

Resting eggs will be separated from sediment and sorted into appropriate groupings for replicate control and exposure test sets. Control sets will be exposed to optimum hatching conditions as determined by a combination of procedures outlined by Bailey et al (2003) and Landrum (pers. comm., NOAA Ballast Water Technology Project, "Disinfection of ballast water with chemical disinfectants."), and other appropriate literature sources. The hatching success of replicate egg sets under optimized laboratory conditions will be compared against hatching success under similar optimum conditions but with exposure to different biocides (chlorination, SeaKleen™, gluteraldehyde, heat, anoxia) at various concentrations or doses. Two series of tests will be conducted for chemical exposures: one using eggs separated from sediment and placed in aqueous culture media, and one in which the eggs are gently mixed into a known sediment matrix which is then covered with aqueous culture media, the latter to explore the biocide effectiveness in the presence of sediments, as found in the bottom of many ballast tanks.

Ballast Reporting Forms for each year from 1991 through 1997, obtained from U.S. Coast Guard archives, will be examined and information extracted for addition to the Vessel Traffic Database obtained from R. Coulatti (University of Windsor). The database will be updated and corrected, and the frequency of misclassification of vessels as NOBOBs will be determined. Ballast Surveys data will be analyzed for ballast intake and discharge amounts, frequency, and locations, while the vessels operate in the Great Lakes.

## Accomplishments for Objective 1

Significant progress has been made in developing sampling and laboratory protocols to conduct the toxicity experiments. However, progress has been slowed by the inconsistencies in finding viable resting eggs from the various sediments that we have sampled. Egg densities were often not sufficient species composition varied to greatly to meet our preferred experimental design. The following tasks have been completed:

- Obtained sediment from Lake Michigan and Muskegon Lake.
- Obtained sediment from various ship ballast tanks of opportunity.
- Obtained sediment from Lake Erie.
- Cultured various species of lake zooplankton in laboratory.
- Extracted resting eggs from sediments.

- Induced resting egg production in laboratory cultures.
- Purchased resting eggs from commercial sources.
- Created new methods to apply standard ecotoxicological protocols to resting eggs.
- Conducted bioassays testing the acute toxicity of SeaKleen on the resting eggs of rotifers, copepods, cladocerans, and brine shrimp.

## Accomplishments for Objective 2

As of November 2004, the Seaway has reported a total of 815 vessels upbound to the Lakes during the 2003 and 2004 shipping season. To date we have received 216 surveys from participating vessels, for a survey return rate of 26.5%. However, the number of responses will increase as surveys may be received up to two months past the 2004 winter closing of the Seaway. Approximately 10 percent of the vessels reporting declared having at least some ballast on board, and 90% of the vessels declared No-ballast-on-Board (NOBOB). These percentages are consistent with the vessel traffic patterns observed during the past decade or so, and continue to point to the importance of understanding to what extent ballast operations of NOBOBs trading within the Great Lakes pose a risk for introduction nonindigenous species.

Ships entering the Great Lakes had traded from a variety of countries prior to entering the Great Lakes (Fig. 1). Each of these countries represents a potential donor region for new nonindigenous species introductions. Western Europe was the predominant region from which ships made their last port of call (typically loading cargo for trade within the Great Lakes) prior to entering the Great Lakes (Fig. 2).

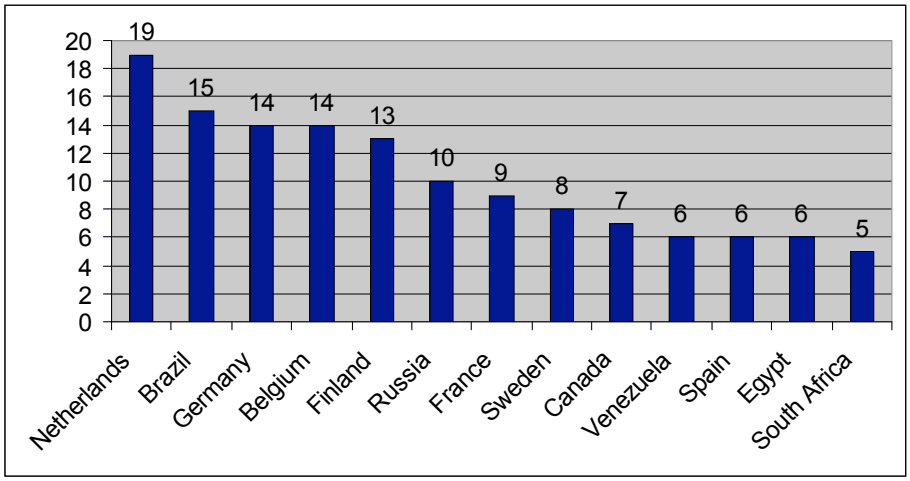


Figure 1. Countries visited by foreign vessels prior to their arrival and trade in the Great Lakes.

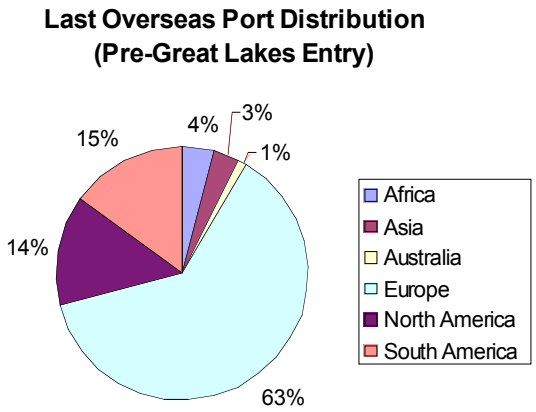


Figure 2. Last Overseas port of call prior to entering the Great Lakes.

## Presentations

Raikow, David. 2004. Biological Invasion in the Great Lakes: Science, Management and Policy", Invited Seminar, Purdue University.

Reid, David. 2004. Results from the survey study were presented to the US Coast Guard at the Great Lakes Marine Community Day, January. Cleveland, Ohio.

## Significant Interactions

USGS Great Lakes Science Center - sediment collected in the Western Basin of Lake Erie provided by Don Schlosser. University of Toledo Lake Erie Center - sediment collected in the Western Basin of Lake Erie provided by Tom Bridgeman. University of Windsor - visited lab and observed sediment handling and egg extraction techniques. Purdue University - visited lab of Chip Blatchley, with whom we are collaborating to test toxicity of UV light.

## Student Participation

The project supported one Great Lakes summer fellow who spent 3 months this past summer working on the resting egg component of the project.

## APPENDIX OF OTHER PUBLICATIONS

Bergmann, T., G.L. Fahnenstiel, S.E. Lohrenz, D.F. Millie and O.M.E. Schofield. 2004. Impacts of a recurrent resuspension event and variable phytoplankton community composition on remote sensing reflectance. *Journal of Geophysical Research* 109 (C10S15):12.

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Landrum, P.F., M. Leppanen, S.D. Robinson, D.C. Gossiaux, G.A. Burton, M. Greenburg, J.V.K. Kukkonen, B.J. Eadie and M.B. Lansing. 2004. Effect of 3,4,3',4'-tetrachlorobiphenyl on the reworking behavior of *Lumbriculus variegatus* exposed to contaminated sediment. *Environmental Toxicology and Chemistry* 23(1):178-186.

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Leppanen, M.T., P.F. Landrum, J.V.K. Kukkonen, M.S. Greenberg, G.A. Burton Jr., S.D. Robinson and D.C. Gossiaux. 2003. Investigating the role of desorption on the bioavailability of sediment-associated 3,4,3',4'-tetrachlorobiphenyl in benthic invertebrates. *Environmental Toxicology and Chemistry* 22(12):2861-2871.

Millie, D.F., G.L. Fahnenstiel, S.E. Lohrenz, H.J. Carrick, T.H. Johengen and O.M.E. Schofield. 2003. Physical-biological coupling in southern Lake Michigan: influence of episodic sediment resuspension on phytoplankton. *Aquatic Ecology* 37:393-408.

Pothoven, S.A., G.L. Fahnenstiel and H.A. Vanderploeg. 2004. Spatial distribution, biomass, and population dynamics of Mysis relicta in Lake Michigan. *Hydrobiologia* 522:291-299.

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